PB-231 267

TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES

P. J. Farrell, et al

Harriman Utility Board

Prepared for:

Environmental Protection Agency

December 1973

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Monitoring, Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

EPA REVIEW NOTICE

This report has been reviewed by the Office of Research and Development, EPA, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price [illegible]

EPA-660/2-73-010
December 1973

TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES

By

P. J. Farrell
L. R. Heble
A. G. Steuhser

Project No. 12130 DBF (formerly 11060 DBF)
Program Element 1B2036

Project Officer

Edmond P. Lomasney
Environmental Protection Agency
1421 Peachtree Street, N.E.
Atlanta, Georgia 30309

Prepared for

OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

PB 231 267

1 Accession Number
W74-06513

2 Subject Field & Group
05D

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 Organization
Harriman Utility Board,
Harriman, Tennessee.

Copy Available from GPO Sup Doc as EP1.23:660/2-73-010, $ 1.40; microfiche from NTIS as PB $1.45

6 Title Treatment of Domestic Wastewater and NSSC Pulp and Paper Mill Wastes,

10 Author(s)
P. J. Farrell
L. R. Heble
A. G. Steuhser

16 Project Designation
EPA Project ~~No. 11060~~ 12130 DBF

21 Note
~~A short appendix covering the pilot plant's operational parameters and results will be made available upon request.~~

22 Citation
Environmental Protection Agency Technology Series report, ~~number~~,
EPA-660/2-73-010, December 1973. 104p, 32 fig, 21 tab, 7 ref

23 Descriptors (Starred First) *Waste water treatment, Sulfites, *Pulp wastes, *Domestic Wastes, ~~*Neutral Sulfite Semichemical (NSSC) Pulp and Paper Mill Waste~~, *Pilot Plant, ~~Primary Clarification, Biofiltration~~, ~~Extended~~ *Aeration, ~~Final Clarification~~, Disinfection, *Filtration, Color, Organic wastes, Solid wastes, Biochemical oxygen demand

25 Identifiers (Starred First)
*Joint Treatment, Organics Removal, Solids Removal, Color Removal, Primary clarification, *Extended aeration, Final clarification, *Biofiltration

27 Abstract

The Harriman Utility Board and the Mead Corporation made a study of the joint treatment of primary clarified domestic waste and neutral sulfite semichemical (NSSC) pulp and paper mill wastes. A pilot plant was constructed and operated from April, 1971 through March, 1972.

The most effective treatment scheme consisted of a biofilter (used as a roughing filter) and an extended aeration system. Color reduction was accomplished by massive lime and chlorine additions due to the color's dependency on pH. Disinfection was optimum when ammonia was mixed with the combined wastes prior to chlorination.

The biofilter's BOD removal efficiency ranged from 3 to 45 percent. Extended aeration's BOD removal efficiency ranged from 24 to 98 percent. (EPA)

~~This report was submitted in fulfillment of Research and Development Grant No. 11060 DBF between the Environmental Protection Agency and the Harriman Utility Board, Harriman, Tennessee.~~

Abstractor P. J. Farrell
Institution Harriman Utility Board, Harriman, Tennessee

WR 102 (REV JULY 1969)
WRSIC

SEND TO: WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON, D. C. 20240

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

☆ U.S. GOVERNMENT PRINTING OFFICE: 1974— 546-314/198

98

ABSTRACT

The Harriman Utility Board and the Mead Corporation made a study of the joint treatment of primary clarified domestic waste and neutral sulfite semichemical (NSSC) pulp and paper mill wastes. A pilot plant was constructed and operated from April, 1971 through March, 1972.

The most effective treatment scheme consisted of a biofilter (used as a roughing filter) and an extended aeration system. Color reduction was accomplished by massive lime and chlorine additions due to the color's dependency on pH. Disinfection was optimum when ammonia was mixed with the combined wastes prior to chlorination.

The BOD removal efficiency of the biofilter ranged from 3 to 45 percent. The BOD removal efficiency of extended aeration ranged from 24 to 98 percent.

This report was submitted in fulfillment of Research and Development Grant No. 11060-DBF between the Environmental Protection Agency and the Harriman Utility Board, Harriman, Tennessee.

Key Words: Domestic waste, neutral sulfite semichemical (NSSC) pulp and paper mill waste, pilot plant, primary clarification, biofiltration, intermediate clarification, extended aeration, color removal, disinfection.

Preceding page blank

TABLE OF CONTENTS

Section Number		Page Number
	Abstract	iii
	Figures	vi
	Tables	vii
I	Conclusions	1
II	Recommendations	2
III	Introduction	3
IV	Objectives	5
V	The Pilot Plant	7
VI	Wastewater Characterization	19
VII	Primary Treatment of NSSC Wastewater	32
VIII	Biofiltration	37
IX	Extended Aeration Treatment	41
X	Final Clarification	64
XI	Color Removal	68
XII	Disinfection	77
XIII	Design Considerations	85
XIV	Acknowledgments	87
XV	References	89
XVI	Glossary of Terms	91
XVII	Appendix	95

Preceding page blank

FIGURES

Figure Number		Page Number
1	Waste Treatment Facilities	4
2	Pilot Plant Sampling Points	8
3	Overall View of the Pilot Plant during Startup Aeration Basin During Startup	9
4	Pilot Plant Flow Diagram: Arrangement No. 1	11
5	Pilot Plant Flow Diagram: Arrangement No. 3	12
6	Pilot Plant Flow Diagram: Arrangement No. 4	13
7	Clarified Domestic Waste BOD vs. Percent Occurrence	20
8	Clarified Domestic Waste COD vs. Percent Occurrence	21
9	Clarified Domestic Waste VSS vs. Percent Occurrence	22
10	Clarified Domestic Waste Total Nitrogen (as N) Concentration vs. Percent Occurrence	23
11	Clarified Domestic Waste Total Phosphate (as PO_4) Concentration vs. Percent Occurrence	24
12	Raw NSSC Waste BOD vs. Percent Occurrence	25
13	Raw NSSC Waste COD vs. Percent Occurrence	26
14	Raw NSSC Waste VSS vs. Percent Occurrence	27
15	Raw NSSC Waste Total Phosphate (as PO_4) vs. Percent Occurrence	28
16	Clarified NSSC Waste BOD vs. Percent Occurrence	35
17	Clarified NSSC Waste VSS vs. Percent Occurrence	36
18	Biofiltration BOD Removal vs. BOD Loading	39
19	Extended Aeration, Arrangement No. 1: BOD Loading vs. Effluent BOD	43
20	Extended Aeration, Arrangement No. 3: BOD Loading vs. Effluent BOD	45
21	Extended Aeration, Arrangement No. 4: BOD Loading vs. Effluent BOD	48

FIGURES (Continued)

Figure Number		Page Number
22	Alpha and Beta vs. Percent NSSC Waste Based on Flow	54
23	Oxygen Transferred vs. BOD Removed	56
24	Oxygen Uptake vs. BOD Removed	60
25	Excess Sludge Optimum Conditions vs. BOD Removed	61
26	Excess Sludge Optimum Conditions vs. Influent VSS	62
27	Final Clarifier BOD vs. TSS Removed	66
28	Final Clarifier Overflow Rate vs. Percent TSS Removed	67
29	Color Removal and pH: 100 percent NSSC Waste	72
30	Color Removal and pH: 50 percent NSSC + 50 percent Wastewater	73
31	Color Removal and Lime + Chlorine: 100 percent NSSC Waste	74
32	Color Removal and Lime + Chlorine: 50 percent NSSC + 50 percent Wastewater	75

TABLES

Table Number		Page Number
1	Description of Sample Points	14
2	Pilot Plant Operation Arrangements and Schemes Description	15
3	Log of Significant Events in Operation of Pilot Unit	16
4	Comparison of Hydraulic and Process Loadings	30
5	Primary Treatment Data NSSC Waste Monthly Averages	33
6	Biofilter Operation Data with Primary Treatment	38
7	Extended Aeration Results (July 14 - August 26, 1971) Arrangement No. 1	42
8	Extended Aeration Results – (October 13, 1971 - March 2, 1972) Arrangement No. 3	46
9	Extended Aeration Results – (March 3 - 29, 1972) Arrangement No. 4	50
10	Alpha and Beta vs. Percentage NSSC Waste	53
11	O_2 Applied vs. BOD Removed	55
12	O_2 Uptake – Aeration Basin Data	58
13	O_2 Uptake vs. BOD Removed	59
14	Final Clarifier Performance (Monthly Average Data)	65
15	Results of Color Removal Studies	69
16	Disinfection Studies – Coliform Baseline Determination	78
17	Disinfection Studies – Application and Sequence Evaluation	79
18	Disinfection Studies – Application, Sequence, and Contact Time Evaluation	80
19	Disinfection Studies – Application, Sequence, and Contact Time Evaluation	81
20	Disinfection Studies – Effluent Coliform after Chlorination	82
21	Disinfection Studies – Effluent Coliform after Chlorination	83

SECTION I

CONCLUSIONS

The conclusions of this report were based upon data developed from the operation of the Harriman Utility Board pilot plant over a one-year period. An extensive sampling and analysis program conducted during the study provided the data to evaluate the pilot plant performance under field conditions. The following are the conclusions reached during this study.

1. As NSSC loading increased from 40 – 90 percent, the effluent BOD increased from 30 – 120 mg/l.

2. Primary clarification of the NSSC wastes followed by high rate biological filtration removed an average of 16 percent of the influent BOD at hydraulic loadings of 50 – 100 mgd/acre.

3. The biofilter – extended aeration combination proved to be the most efficient treatment scheme.

4. High NSSC to domestic wastewater ratios reduced the effectiveness of the optimum treatment scheme.

5. Both primary and secondary clarification improved the overall BOD removal efficiency.

6. Color was found to be pH dependent and required massive lime and chlorine additions for effective removal. Lime requirements would be approximately 194 tons per million gallons of wastewater.

7. Maximum disinfection was achieved by addition of 40 mg/l ammonia and 20 mg/l chlorine. Contact times greatly affected the degree of disinfection. A five-minute contact time after the ammonia addition followed by a 15-minute contact time after chlorination proved to be most effective.

SECTION II

RECOMMENDATIONS

As a result of this study, it is recommended that:

1. Primary clarification of the raw NSSC wastewater followed by biofiltration of the combined NSSC-domestic wastewater precede extended aeration of the wastewaters.
2. Greater than 90 percent NSSC for the combined wastewater, based on BOD loading, should be avoided.
3. Disinfection can be best achieved by addition of ammonia and chlorine.
4. Additional work is needed on lime recycle before massive lime treatment is considered as an economical means of color removal.

SECTION III

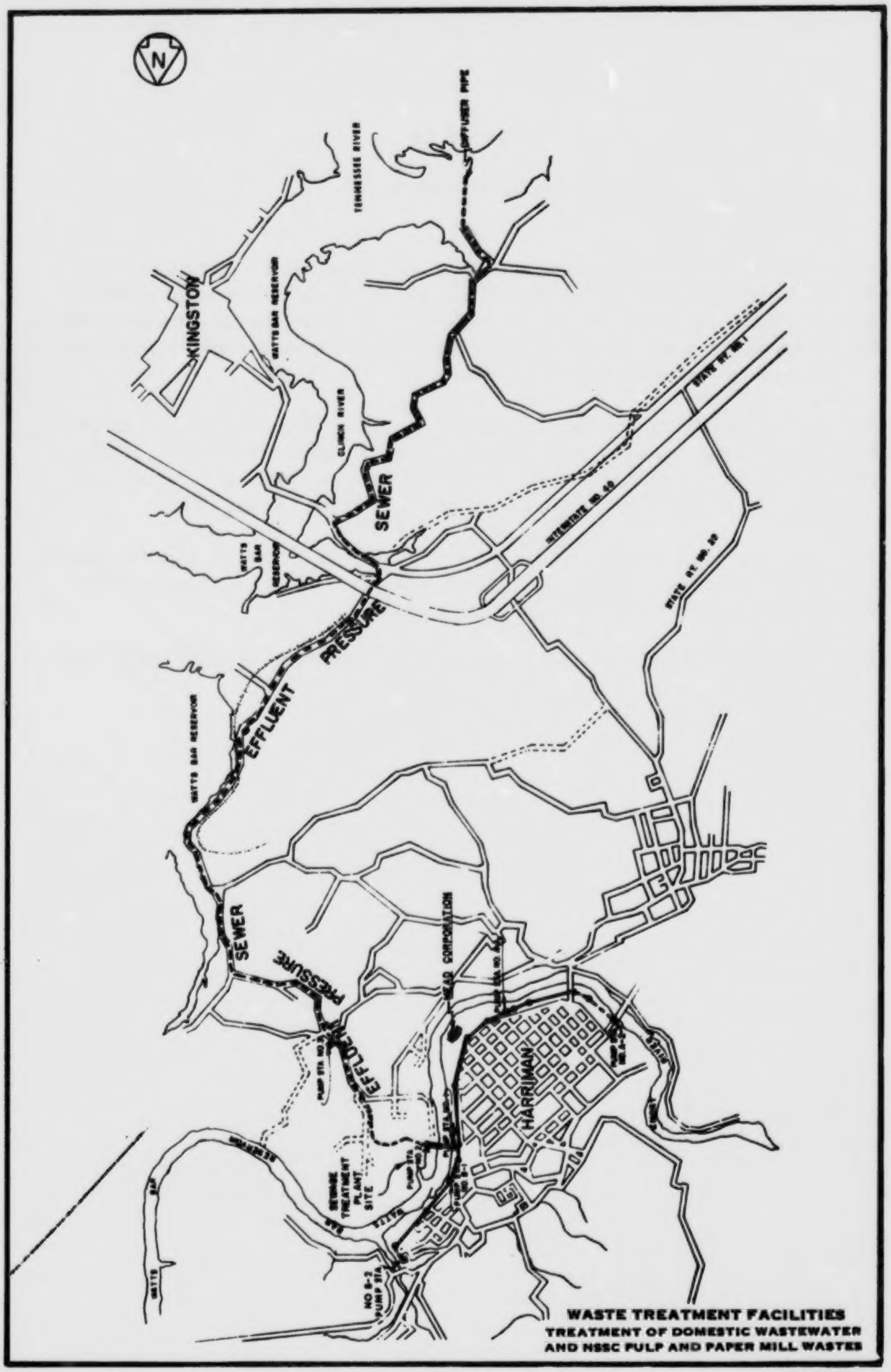
INTRODUCTION

A joint treatment study of domestic wastewater and neutral sulfite semichemical (NSSC) pulp and paper mill wastes was conducted with the aid of an Environmental Protection Agency Research and Development Grant (11060-DBF). The main purpose of the study was the feasibility of a joint treatment scheme. Joint treatment could provide a means for regionalization of treatment and economy of scale.

A pilot plant was constructed adjacent to the Harriman Utility Board, Harriman, Tennessee primary wastewater treatment plant. The pilot plant, completed in February of 1971, provided a means of evaluating a variety of hydraulic and organic loadings under controlled conditions. The pilot plant was operated from April, 1971 through March, 1972.

The NSSC waste was available at the pilot plant site (see Figure 1) from the Mead Corporation, Harriman, Tennessee. The primary wastewater effluent was channeled from the Harriman wastewater treatment plant to the pilot plant.

A short appendix covering the pilot plant's operational parameters and results will be made available upon request.


N
KINGSTON
WATTS BAR RESERVOIR
TENNESSEE RIVER
CLINCH RIVER
DIFFUSER PIPE
SEWER
PRESSURE
EFFLUENT
INTERSTATE NO. 40
STATE RT. NO. 1
STATE RT. NO. 29
MEAD CORPORATION
HARRIMAN
SEWAGE TREATMENT PLANT SITE
PUMP STA. NO. 3
NO. S-2 PUMP STA.
WATTS BAR

WASTE TREATMENT FACILITIES
TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES

FIGURE 1.

SECTION IV

OBJECTIVES

The general objectives of this project were to construct and operate a pilot plant, evaluate the treatability of combined wastewater from domestic sources and an integrated neutral sulfite semichemical (NSSC) pulp and paper mill, and develop design criteria applicable to its treatment.

The detailed objectives include the following:

1. Establish design criteria, operating parameters and efficiencies of the following secondary processes for the treatment of combined municipal and NSSC pulp and paper mill wastewater in varying proportions:
    (a) Extended aeration
    (b) High-rate biological filtration
    (c) High-rate biological filtration followed by extended aeration
2. Investigate the effects of a varying ratio of NSSC wastes to municipal wastewater on the above treatment processes.
3. Determine the supplemental nutrient requirements for the above treatment processes.
4. Evaluate the requirement for primary clarification of NSSC wastes in conjunction with the above treatment processes.
5. Investigate and evaluate the role of secondary clarification in the overall reduction of biochemical oxygen demand (BOD) in the above treatment processes.
6. Investigate color reduction of the combined NSSC-municipal wastewater by the massive lime dosage technique and other methods. Evaluate color reduction methods in the laboratory.
7. Investigate the disinfection of combined municipal wastewater and NSSC pulp and paper mill wastes after treatment by the proposed methods. Investigatory work is to include laboratory bench scale tests to compare efficiencies

and costs of various agents for reducing the concentration of coliform group organisms in treated wastewater. Such common agents as chlorine and chloramines are to be employed. Investigate the effects of concentration, contact time, etc., during the bench tests to establish optimum conditions for acceptable levels of bacterial reduction.

SECTION V

THE PILOT PLANT

Description

A flow diagram of the pilot plant as constructed is shown in Figure 2. A photograph of the overall pilot unit is shown in Figure 3. The pilot unit was sized to treat 15 to 200 gallons per minute (gpm) of combined NSSC-municipal wastewater.

As indicated in the process flow diagram, the NSSC wastes were clarified in a primary clarifier prior to being combined with the municipal wastewater. The primary clarifier is 11.5 feet in diameter and has a 7.1-foot sidewater depth (SWD). Primary sludge should be withdrawn at least once every hour.

A double weir box was used to measure the clarified NSSC and municipal wastewater. A 1,400-gallon capacity blend tank was used to combine the wastewater. Nitrogen and phosphorus, as needed, were pumped into the blend tank by a controlled volume pump (20.8 gph maximum capacity) from a 335-gallon nutrient feed tank.

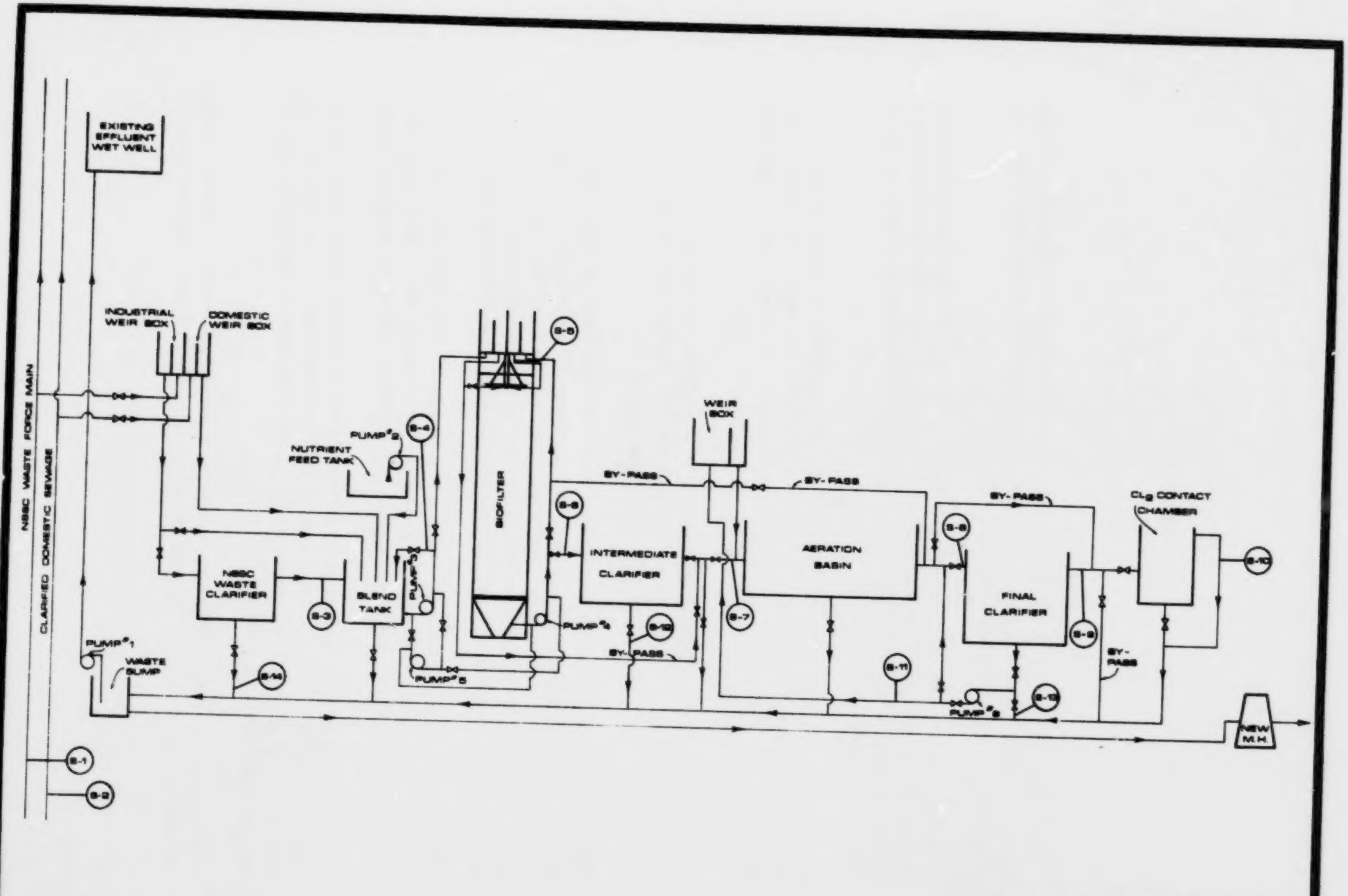
The blended waste was pumped by a 150 gpm transfer pump to a weir box on top of the trickling filter which is 39 feet tall and 9 feet in diameter. This weir box measured the flow of raw waste to the trickling filter or to the aeration basin.

The trickling filter was a high rate trickling filter with approximately 1,200 cubic feet of synthetic media. A separate weir box was used to measure the recycled flow to the trickling filter. An intermediate clarifier, 15 feet in diameter and with a 14.4-foot SWD, was used to clarify the trickling filter effluent. The sludge removed from the intermediate clarifier was discharged to a waste sump and the supernatant was discharged to the aeration basin.

The activated sludge system was comprised of an aeration basin and final clarifier. The aeration basin had a 120,000-gallon capacity and was equipped with a 15 hp blower-draft diffused tube aeration system. A photograph of the aeration basin is also shown in Figure 3.

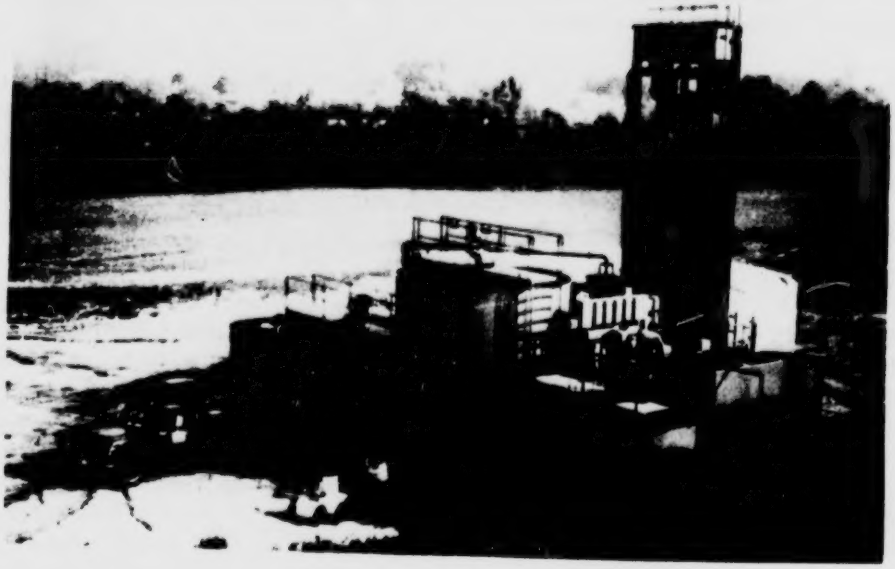
A weir box was provided to measure recirculated flow from the final clarifier to the aeration basin. The clarifier had a 15-foot diameter and 13-foot SWD, and was equipped with a 180 gpm return sludge pump. The pump was used to return the sludge to the aeration basin weir box or waste sludge to the waste sump.

Effluent from the final clarifier was chlorinated in a 4,200-gallon capacity chlorine contact chamber equipped with a 3.2 gph maximum capacity controlled volume pump for

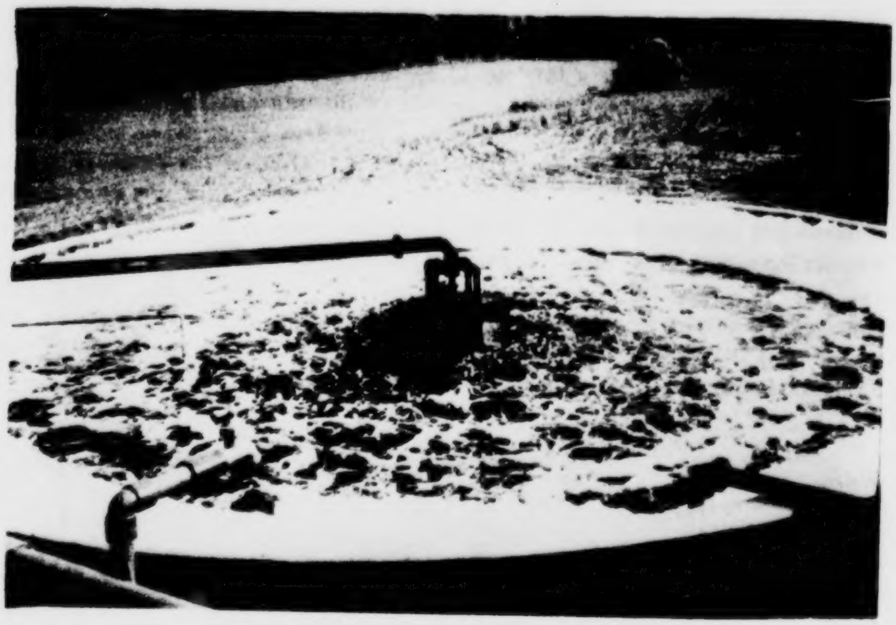

EXISTING EFFLUENT WET WELL
NSSC WASTE FORCE MAIN
CLARIFIED DOMESTIC SEWAGE
INDUSTRIAL WEIR BOX
DOMESTIC WEIR BOX
PUMP #1
WASTE SUMP
NSSC WASTE CLARIFIER
NUTRIENT FEED TANK
PUMP #2
BLEND TANK
PUMP #3
PUMP #5
BIOFILTER
PUMP #4
INTERMEDIATE CLARIFIER
BY-PASS
WEIR BOX
AERATION BASIN
FINAL CLARIFIER
PUMP #6
Cl_2 CONTACT CHAMBER
NEW M.H.
S-1
S-2
S-3
S-4
S-5
S-6
S-7
S-8
S-9
S-10
S-11
S-12
S-13
S-14

PILOT PLANT SAMPLING POINTS
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

FIGURE 2



OVERALL VIEW OF THE PILOT PLANT DURING STARTUP



PILOT PLANT AERATION BASIN DURING STARTUP

TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

FIGURE 3

disinfection. Ammonia feed facilities were also available for final effluent disinfection. The waste sump was a 2,000-gallon tank with a 200 gpm capacity pump which pumped the waste to an existing effluent wet well.

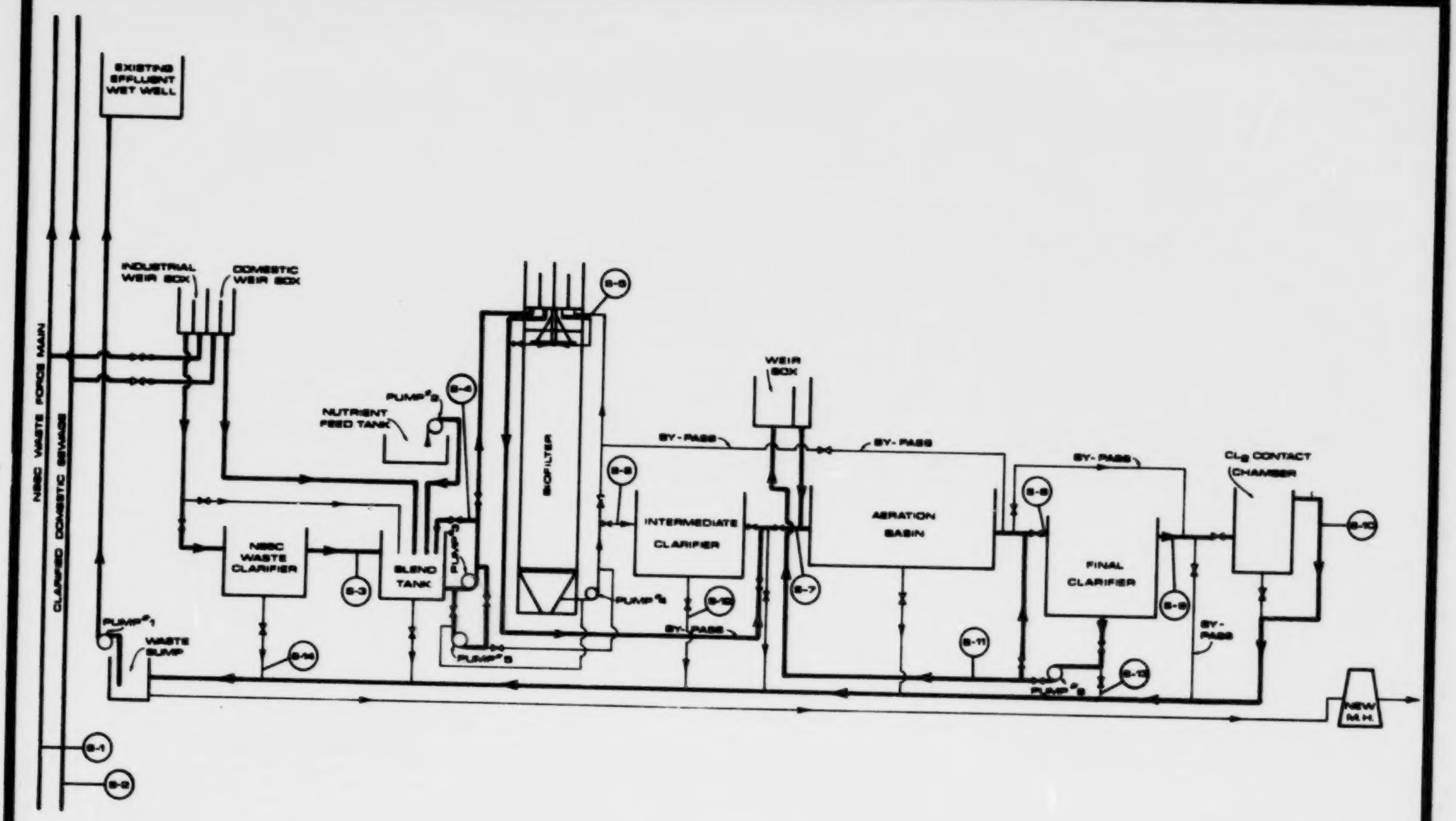
Piping and valves were provided to bypass the primary clarifier, the trickling filter, the intermediate clarifier and aeration basin, the final clarifier and the chlorine contact chamber. This added flexibility was required to evaluate the performance of the unit processes in the pilot system.

Operation

The pilot plant was operated under three arrangements, Nos. 1, 3, and 4 (see Figures 4, 5, and 6). Arrangement 1 consisted of primary clarification of the NSSC waste before blending with the clarified domestic wastewater. The mixture was then admitted to the aeration basin, final clarifier and the chlorination chamber. Arrangement 3 consisted of primary clarification of the NSSC waste before blending with domestic wastewater. The mixture was then fed to the biofilter where the organic and hydraulic loadings were varied. From the biofilter, the wastewater went to an intermediate clarifier, then into the aeration basin, final clarifier and the chlorination chamber. Arrangement 4 was identical with Arrangement 3 with one exception: the NSSC waste was not subjected to primary clarification before being introduced to the biofilter.

Arrangement 2 was discontinued in the study when it was determined that supplemental nutrient addition was not necessary for adequate treatment of the combined wastes. These arrangements were divided into a total of 14 schemes (see Table 2). Figure 2 shows the sampling points used in monitoring the operation of the unit and Table 1 describes the sampling points. The sampling cocks necessary for sample draw-off should be located on the top of the pipes to avoid solids that will settle to the bottom of the pipes. This would reduce the chances of settled solids influencing the analyses of the sample. The arrangements and schemes described in Table 2 were evaluated by monitoring these sample points under the variety of organic and hydraulic loadings indicated.

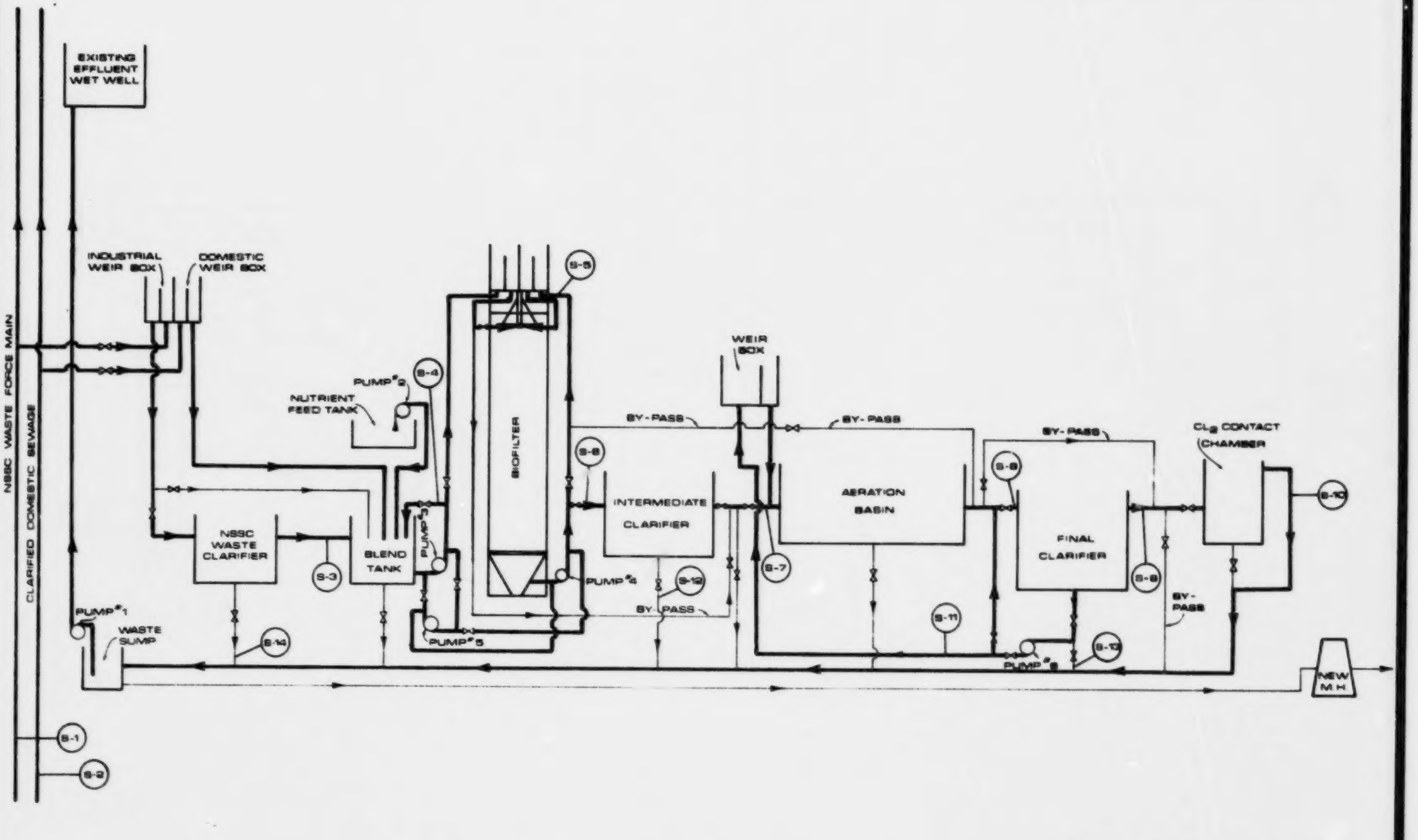
A chronological summary of major events during the operation of the pilot system is given in Table 3. This shows times of changes in the arrangements and schemes of the unit and significant occurrences affecting its operation.


NBSC WASTE FORCE MAIN
CLARIFIED DOMESTIC SEWAGE
EXISTING EFFLUENT WET WELL
INDUSTRIAL WEIR BOX
DOMESTIC WEIR BOX
NUTRIENT FEED TANK
PUMP #2
S-4
S-5
BIOFILTER
WEIR BOX
BY-PASS
BY-PASS
BY-PASS
CL_2 CONTACT CHAMBER
S-6
INTERMEDIATE CLARIFIER
AERATION BASIN
S-8
FINAL CLARIFIER
S-10
NBSC WASTE CLARIFIER
BLEND TANK
PUMP #3
S-3
PUMP #4
S-12
BY-PASS
S-7
S-11
S-9
BY-PASS
PUMP #1
WASTE SUMP
S-14
PUMP #5
PUMP #6
S-13
NEW M.H.
S-1
S-2

**PILOT PLANT FLOW DIAGRAM:
ARRANGEMENT NO. 1**

**TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES**

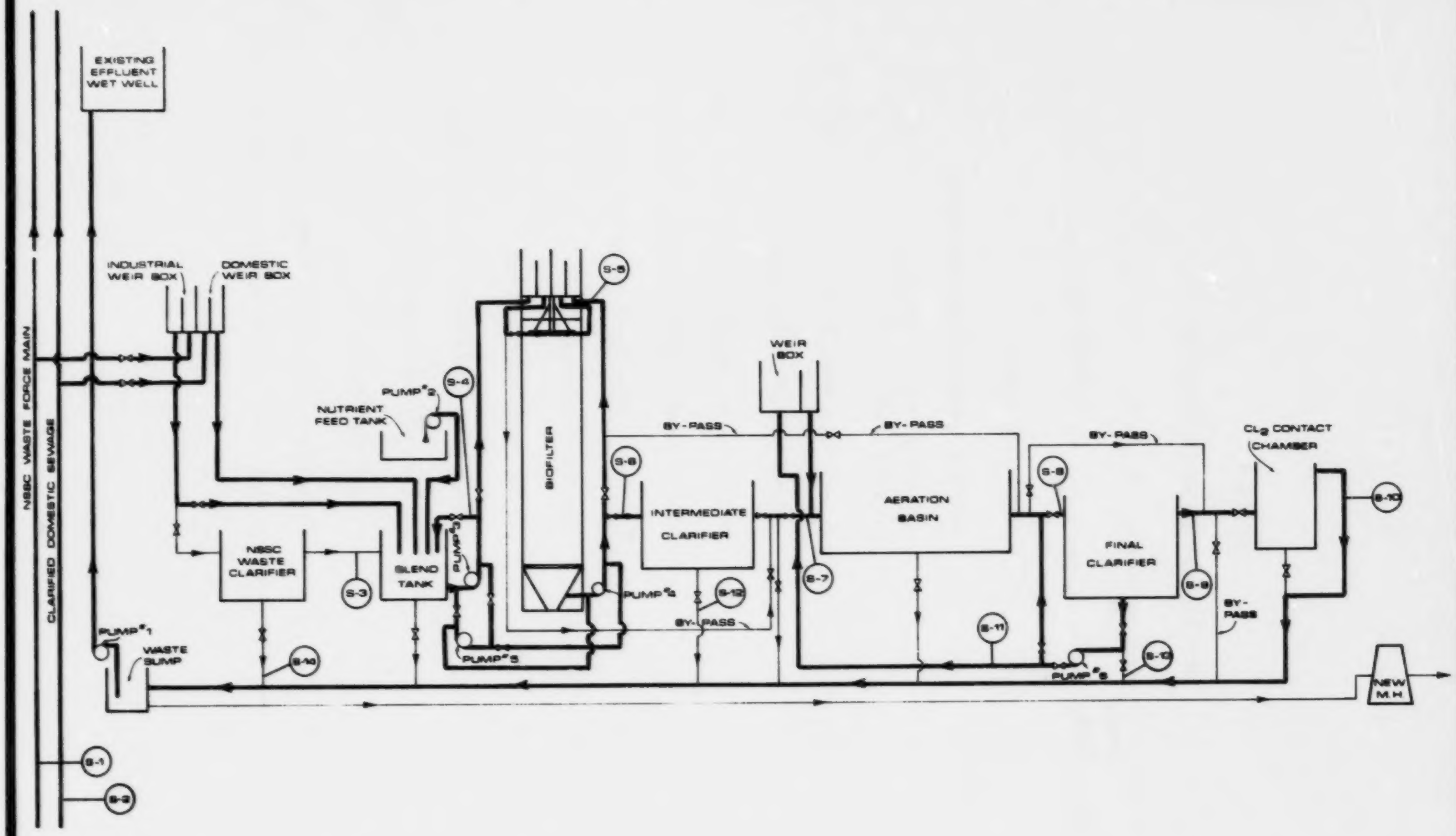
FIGURE 4


NSSC WASTE FORCE MAIN
CLARIFIED DOMESTIC SEWAGE
EXISTING EFFLUENT WET WELL
INDUSTRIAL WEIR BOX
DOMESTIC WEIR BOX
PUMP #1
WASTE SUMP
S-1
S-2
NSSC WASTE CLARIFIER
S-14
S-3
BLEND TANK
NUTRIENT FEED TANK
PUMP #2
S-4
PUMP #3
PUMP #5
BIOFILTER
S-5
PUMP #4
S-6
INTERMEDIATE CLARIFIER
S-12
BY-PASS
WEIR BOX
S-7
AERATION BASIN
S-11
S-8
FINAL CLARIFIER
S-9
PUMP #6
S-13
CL2 CONTACT CHAMBER
S-10
NEW M H

PILOT PLANT FLOW DIAGRAM: ARRANGEMENT NO. 3

TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES

FIGURE 5


NSSC WASTE FORCE MAIN
CLARIFIED DOMESTIC SEWAGE
EXISTING EFFLUENT WET WELL
INDUSTRIAL WEIR BOX
DOMESTIC WEIR BOX
S-5
PUMP #2
S-4
NUTRIENT FEED TANK
BIOFILTER
BY-PASS
WEIR BOX
BY-PASS
BY-PASS
CL2 CONTACT CHAMBER
S-6
INTERMEDIATE CLARIFIER
AERATION BASIN
S-8
FINAL CLARIFIER
S-10
NSSC WASTE CLARIFIER
BLEND TANK
PUMP #3
S-3
S-7
S-9
PUMP #4
S-12
BY-PASS
BY-PASS
S-11
PUMP #1
WASTE SUMP
S-14
PUMP #5
PUMP #6
S-13
NEW M.H.
S-1
S-2

PILOT PLANT FLOW DIAGRAM: ARRANGEMENT NO. 4

TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES

FIGURE 6

TABLE 1

DESCRIPTION OF SAMPLE POINTS

Sample Point	Description
S-1	NSSC Waste Influent
S-2	Clarified Domestic Wastewater Influent
S-3	NSSC Waste Clarifier Effluent (Influent to Blend Tank)
S-4	Recycle From Blend Tank
S-5	Influent to Biofilter From Blend Tanks
S-6	Influent to Intermediate Clarifier From Biofilter
S-7	Influent Aeration Basin From Intermediate Clarifier
S-8	Influent Final Clarifier From Aeration Basin
S-9	Final Clarifier Effluent
S-10	Cl_2 Contact Chamber Effluent
S-11	Recycle From Final Clarifier to Aeration Basin
S-12	Sludge From Intermediate Clarifier
S-13	Sludge From Final Clarifier
S-14	Sludge From Primary NSSC Waste Clarifier

TABLE 2

PILOT PLANT OPERATION

ARRANGEMENTS AND SCHEMES DESCRIPTION

Arrangement Number	Scheme Number	Description
1	1	Nutrient Optimization
1	2	MLSS Optimization – 300 mg/l
1	3	MLSS Optimization – 400 mg/l
1	4	MLSS Optimization – 2,000 mg/l
1	5	Waste Ratio Optimization – 63% NSSC, 37% DS
1	6	Waste Ratio Optimization – 95% NSSC, 5% DS
3	9	Hydraulic Loading to Biofilter Optimization
3	10	Hydraulic Loading to Biofilter Optimization
3	11	Hydraulic Loading to Biofilter Optimization
3	12	Organic Loading of Biofilter Optimization – 500# BOD/cu ft
3	13	Organic Loading of Biofilter Optimization – 750# BOD/cu ft
3	14	Waste Ratio Optimization – 95% NSSC, 5% DS
3	15	Waste Ratio Optimization – 100% NSSC, 0% DS
4	16	Effect of Primary Clarification – Raw NSSC Waste Used

TABLE 3

LOG OF SIGNIFICANT EVENTS IN OPERATION OF PILOT UNIT

Date	Event	Remarks
2/15/71	Construction completed	--
4/1/71	Arrangement 1, Schemes 1 and 2 started	An excess of nutrients in the raw waste prevented determination of optimum nutrient levels.
5/26/71	--	VSS analyses using glass filters were initiated at all sample points.
5/27/71	Arrangement 1, Scheme 3 started	Sludge return from final clarifier changed to an intermittent basin.
7/13/71	--	Soluble BOD analyses replaced total BOD in effluent monitoring.
7/19/71	Arrangement 1, Scheme 4 started	MLSS of aeration basin increased to 4,000 mg/l by addition of anaerobic digester sludge.
8/8/71	Arrangement 1, Scheme 5 started	NSSC to municipal wastewater ratio was varied.
9/10/71	Arrangement 1, Scheme 6 started	High proportion of NSSC to municipal wastewater caused removal efficiency to drop considerably so Schemes 7 and 8 were abandoned. Changeover to grab sampling at selected sample points was started.

TABLE 3 (Continued)

LOG OF SIGNIFICANT EVENTS IN OPERATION OF PILOT UNIT

Date	Event	Remarks
10/2/71	Arrangement 3, Scheme 9 started	Acclimation period was allowed for growth on the biofilter. Laboratory oxygen studies completed and disinfection studies started.
11/4/71	Arrangement 3, Schemes 10 and 11 started	Schemes 10 and 11 were run together because of difficulty in controlling the hydraulic loading.
11/18/71	Arrangement 3, Scheme 13 started	Difficulties remained in controlling the MLVSS.
12/24/71	--	Intermediate clarifier sludge concentrator was shut down due to mechanical difficulties.
1/10 – 1/12/72	--	Air blower filter was dirty causing low air delivery to aeration basin. Filter was cleaned and normal operation resumed.
1/20/72	Arrangement 3, Scheme 14 started	Some mechanical problems in aeration basin and biofilter were cleared up.
1/25/72	--	Tap water had to be added to the NSSC waste in order to get the biofilter distribution arm rotating.
2/11/72	Arrangement 4, Scheme 15 started	--
2/12/72	--	Air blower filter cleaned again due to low air delivery to aeration basin.

TABLE 3 (Continued)

LOG OF SIGNIFICANT EVENTS IN OPERATION OF PILOT UNIT

Date	Event	Remarks
2/14/72	--	Sump pump clogged with sludge and failed to run for undetermined time.
3/1/72	--	Sloughing off of solids from biofilter resulted in sharp rise in solids at Station 6.
3/3/72	Arrangement 4, Scheme 16 started	--
3/6/72	--	Municipal wastewater flow to blend tank reduced due to overflow.
3/15/72	--	Air blower filter cleaned again.
3/20/72	--	Dilution ratio used in disinfection studies changed to lower value.

SECTION VI

WASTEWATER CHARACTERIZATION

Samples of the clarifier domestic waste and raw NSSC waste were collected by plant personnel and analyzed at the site. The data were summarized and evaluated statistically. Subsequent subsections describe the results of these evaluations.

Clarified Domestic Wastewater

The BOD, COD, VSS, total nitrogen and total phosphate data from April, 1971, through March, 1972, were statistically evaluated. Figures 7, 8, 9, 10 and 11 give the respective results of these analyses. The evaluations showed that constituents were present in the following geometric mean concentrations:

Parameter	Concentration (mg/l)
BOD	133
COD	360
VSS	54
Total Nitrogen (as N)	24
Total Phosphate (as PO_4)	26

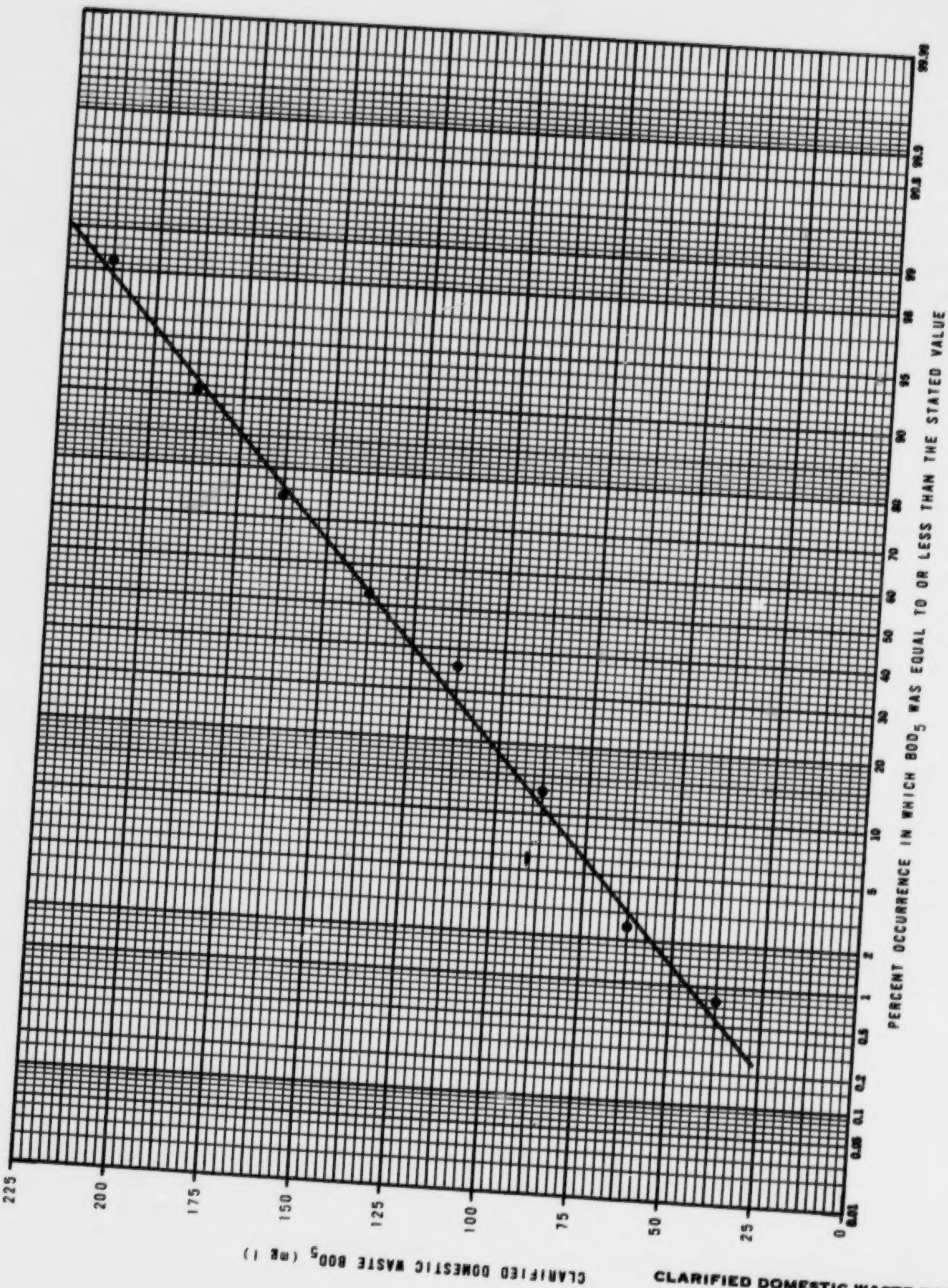
All values for BOD referred to in this report are based upon standard 5-day, 20°C. test procedures.

The other constituents of pH, temperature, total solids, settleable solids, etc., fell within the ranges for domestic wastewater. The pH varied from 6.5 to 7.5, the total solids ranged from 150 to 690 mg/l, and temperature was from 9° to 29° C. depending upon the season. From the characterization data, it can be seen that the domestic wastewater handled by the pilot unit was typical of a clarified domestic wastewater.

Raw NSSC Waste

A summary of statistical analyses of constituents in the raw NSSC wastewater is given in Figures 12 through 15. These analyses include data for the period from October, 1971, through March, 1972.

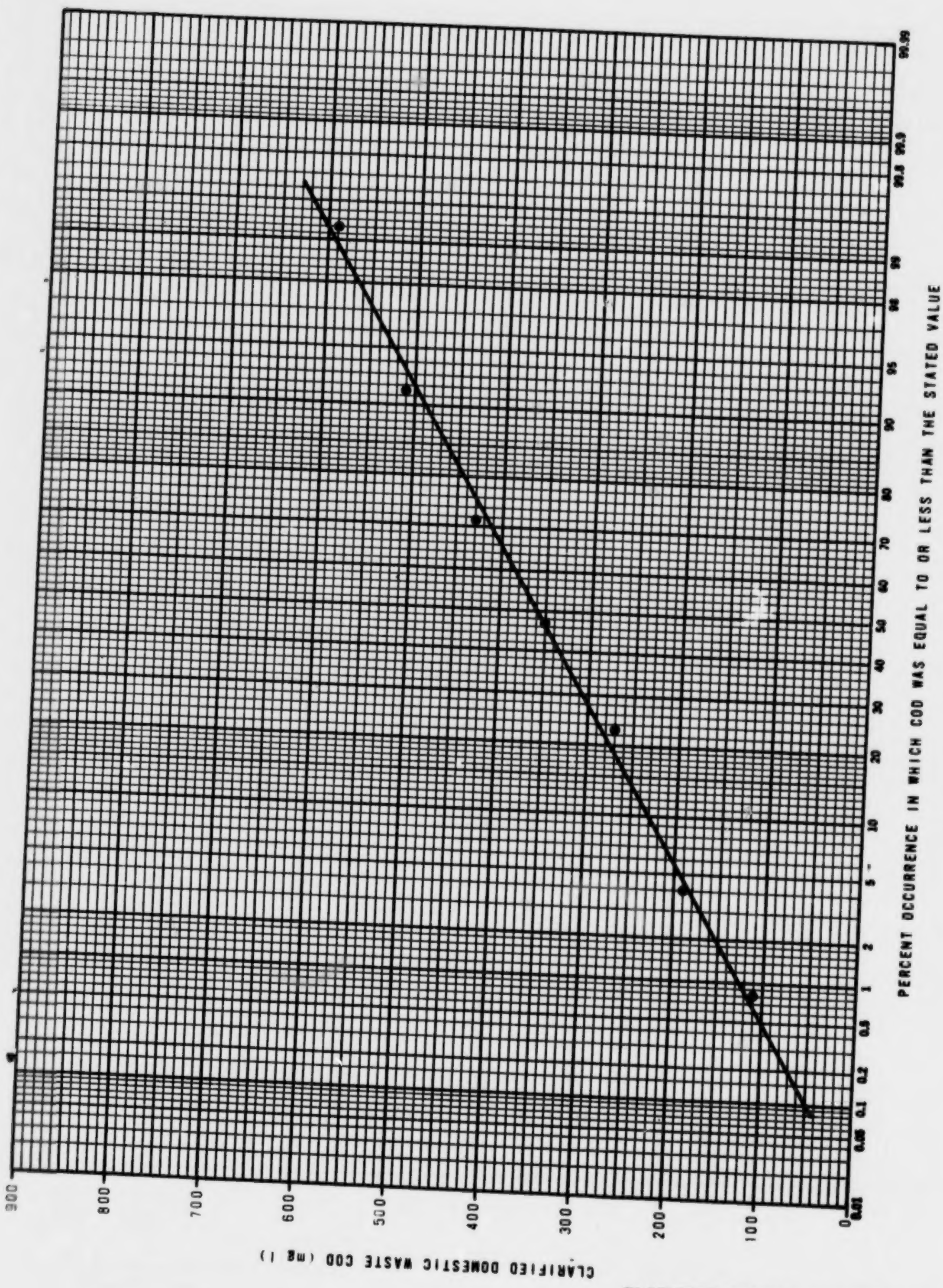
The data were evaluated for the months of October through March because these results were more representative of the waste treated by the pilot unit. The months of April through September were atypical because the NSSC raw wastewater sampling point (from April to October) was located where it gave erroneously high solids. This location was changed at the end of September, 1971.



CLARIFIED DOMESTIC WASTE BOD$_5$ VS. PERCENT OCCURRENCE

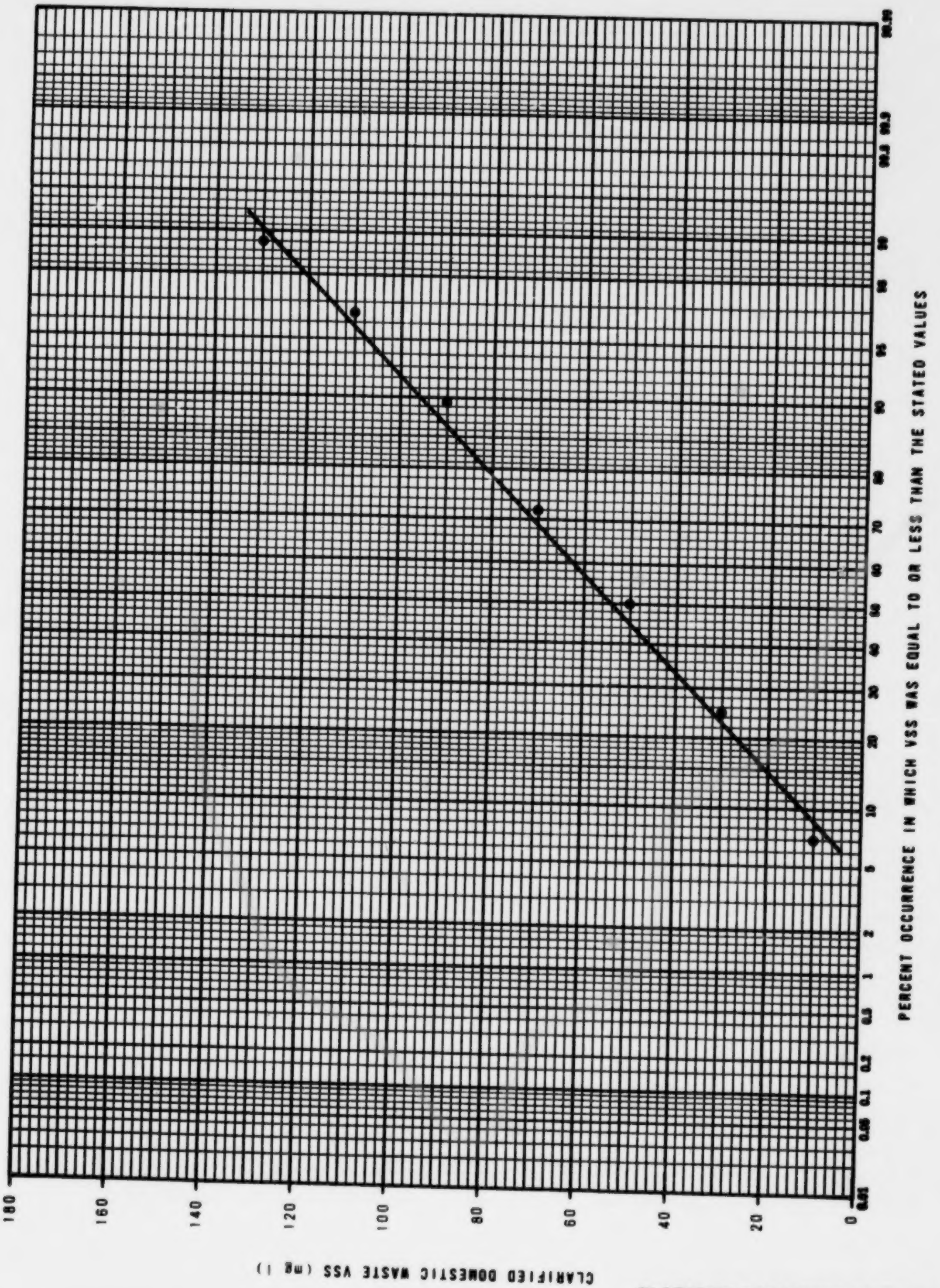
TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES

FIGURE 7



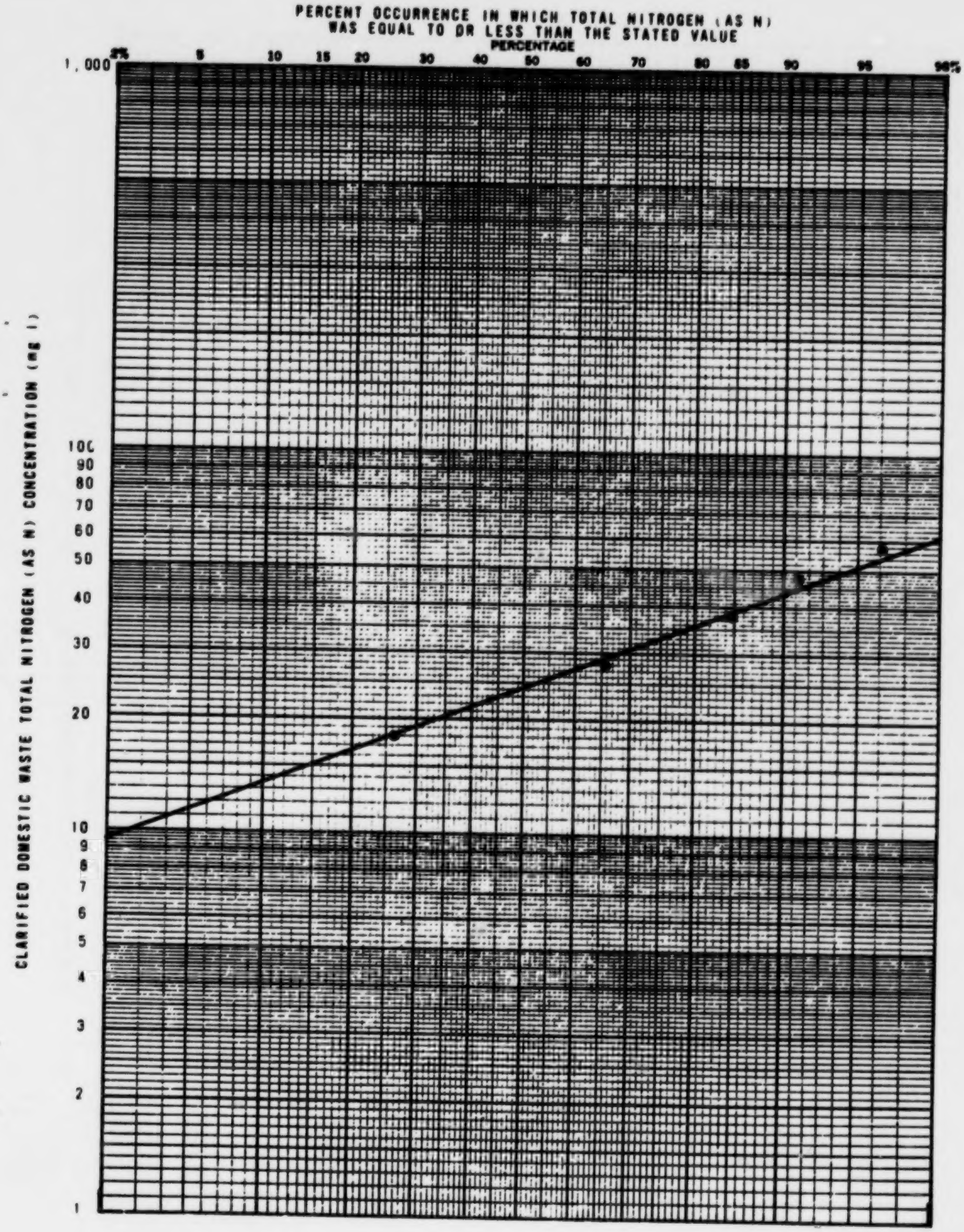
CLARIFIED DOMESTIC WASTE COD
VS. PERCENT OCCURRENCE
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

FIGURE 8



CLARIFIED DOMESTIC WASTE VSS VS.
PERCENT OCCURRENCE
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

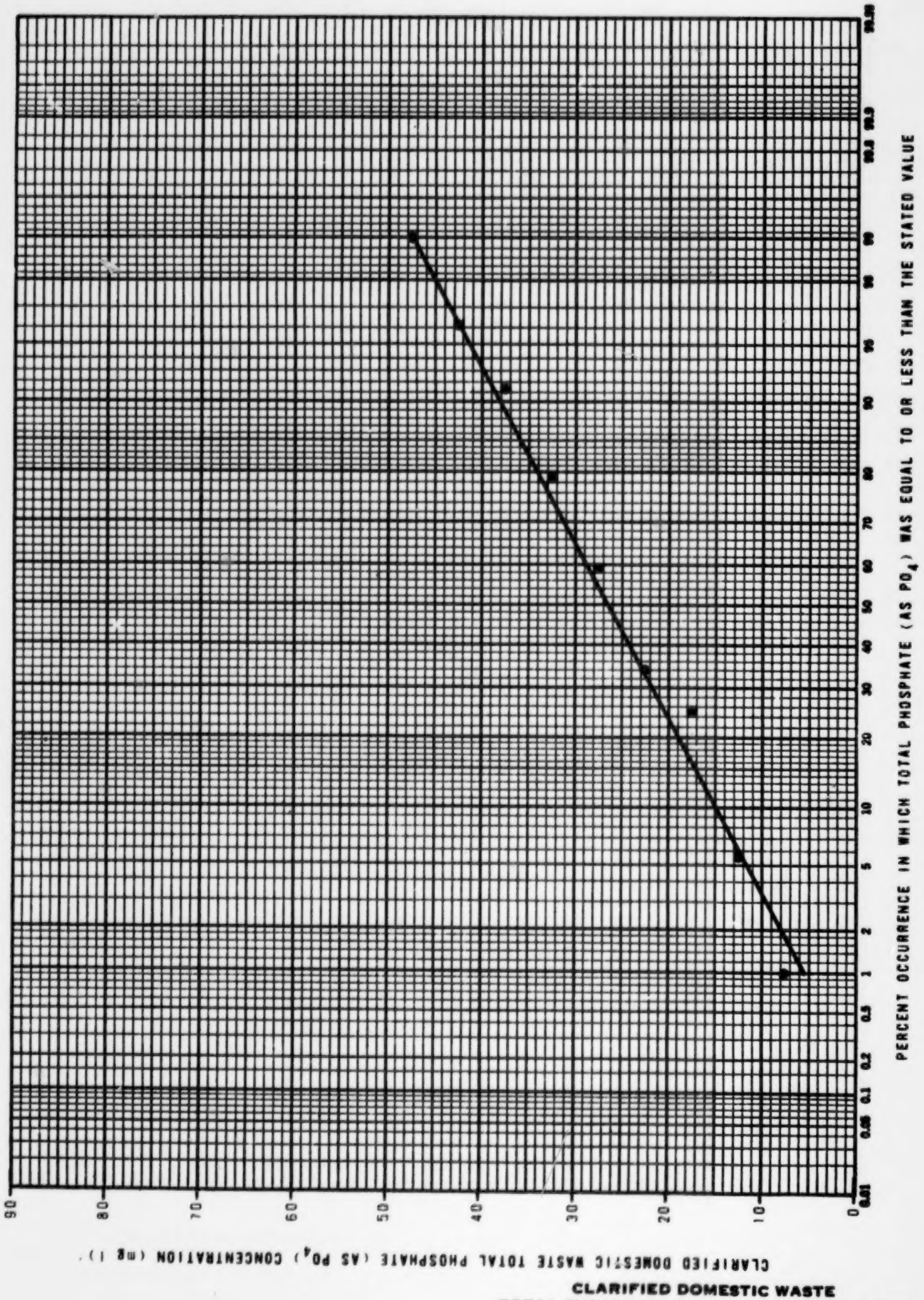
FIGURE 9



CLARIFIED DOMESTIC WASTE
TOTAL NITROGEN (AS N) CONCENTRATION
VS. PERCENT OCCURRENCE

TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

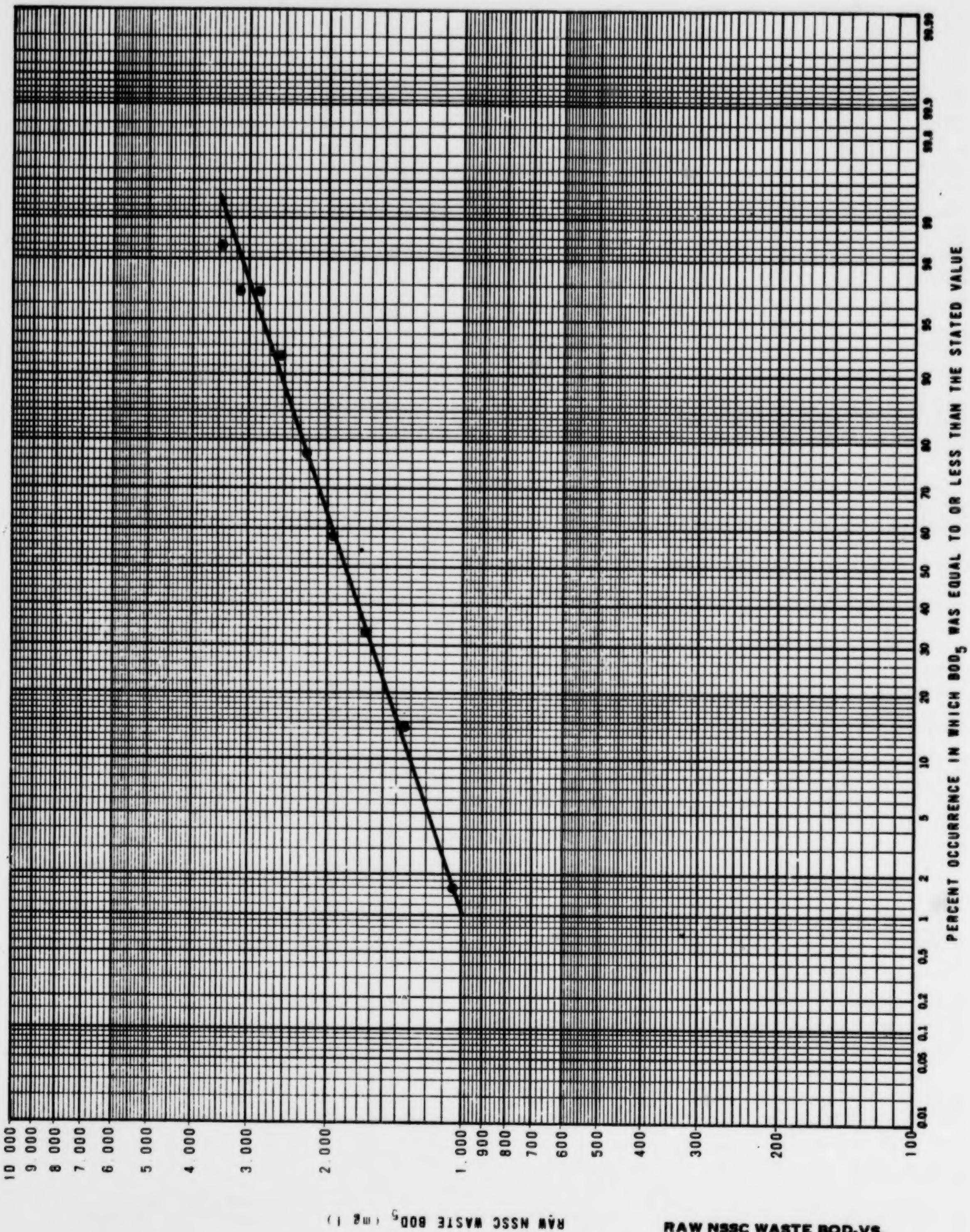
FIGURE 10



CLARIFIED DOMESTIC WASTE
TOTAL PHOSPHATE (AS PO_4) CONCENTRATION
VS. PERCENT OCCURRENCE

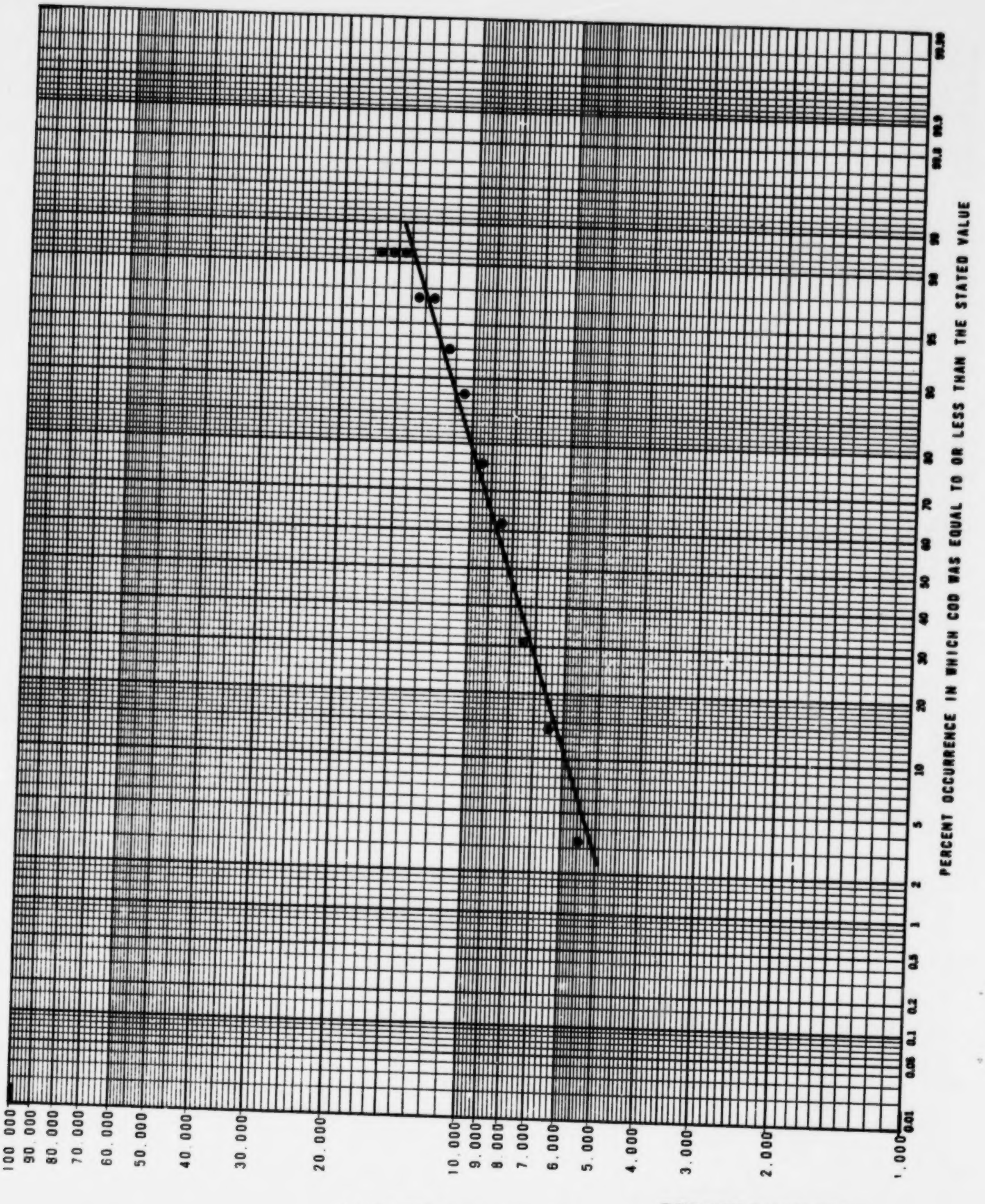
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

FIGURE 11



RAW NSSC WASTE BOD_5 VS. PERCENT OCCURRENCE
TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES

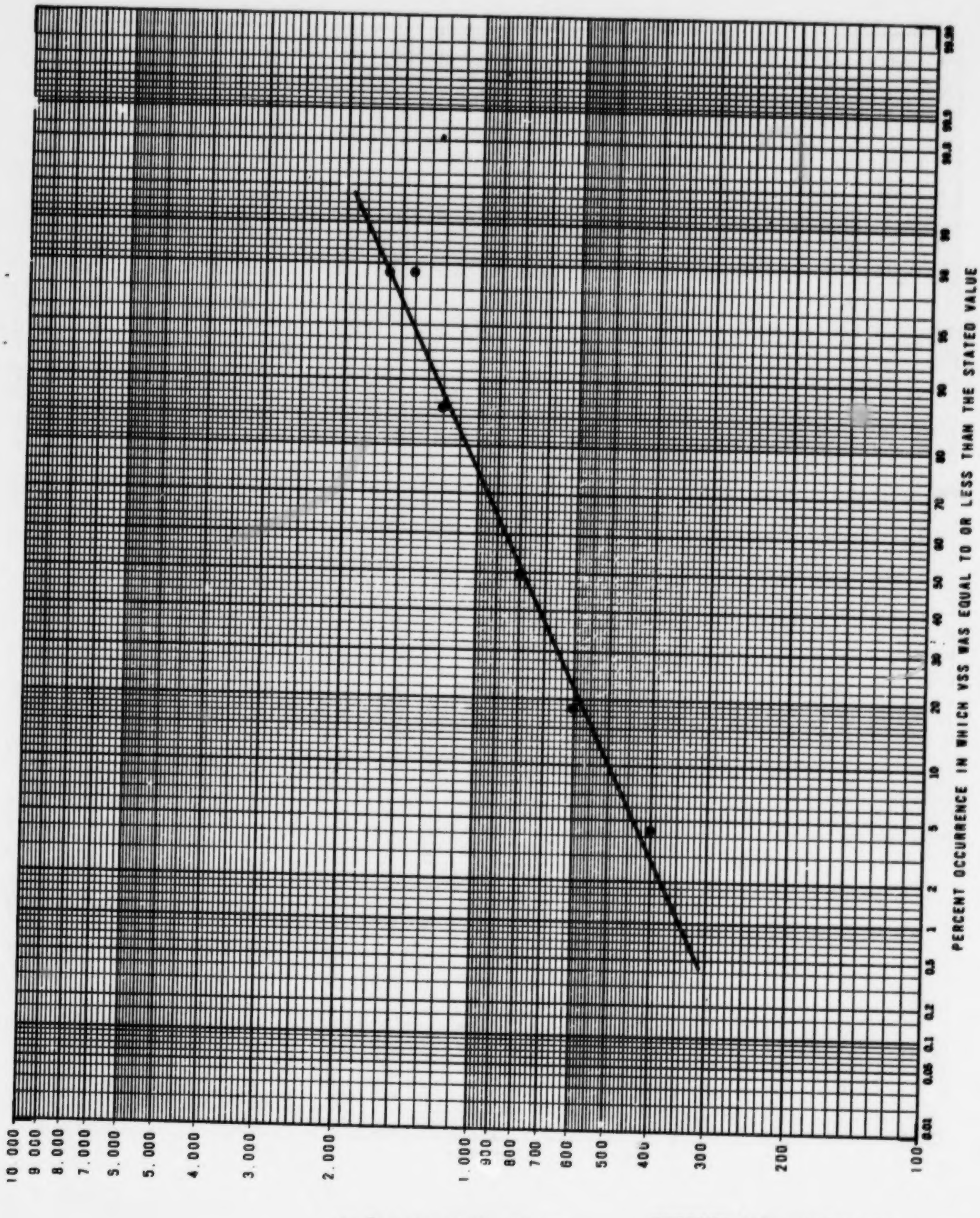
FIGURE 12



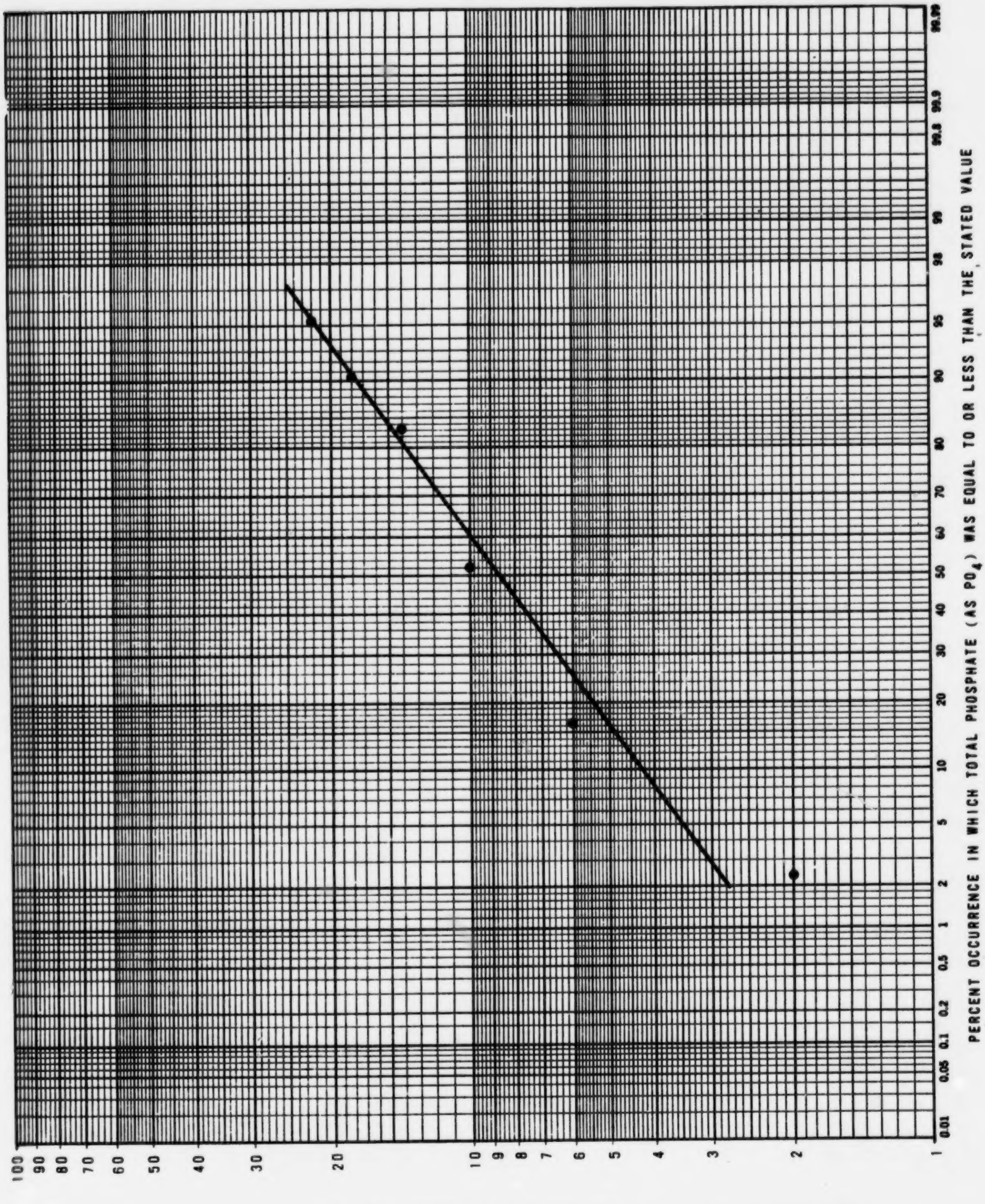
RAW NSSC WASTE COD VS. PERCENT OCCURRENCE

TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES

FIGURE 13



OCTOBER, 1971 - MARCH, 1972
RAW NSSC WASTE VSS VS.
PERCENT OCCURRENCE
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES
FIGURE 14



RAW NSSC WASTE
TOTAL PHOSPHATE (AS PO_4) VS.
PERCENT OCCURRENCE
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

FIGURE 15

Analysis of waste constituents indicated the following geometric mean concentrations:

Parameter	Concentration (mg/l)
BOD	1,850
COD	8,200
VSS	800
Phosphate (as PO_4)	8.6

The BOD and COD values were considerably higher than those for the domestic waste. Since the COD and BOD were not filtered, the results reflected oxygen demand due to both soluble organics and suspended solids in the wastewater. The high volatile suspended solids were due primarily to the presence of cellulose fibers in the pulp and paper mill wastewater.

The relatively high BOD of the NSSC wastewater and low BOD of the clarified domestic wastewater resulted in high industrial process loadings to the pilot system. Table 4 shows a comparison of hydraulic loadings and corresponding process loadings. The basis for the comparison was the geometric mean BOD for the NSSC wastewater and the municipal wastewater, or a 1,850 and 135 mg/l BOD for the industrial and domestic wastewaters before blending. It can be seen that on the basis of equal hydraulic loadings that a considerably higher industrial process loading is handled by the plant.

The other constituents fall in the following ranges:

Constituent	Concentration (mg/l) *
pH	6.3 – 7.7
Total Solids	7,670 – 18,300
Settleable Solids	10 – 900
Temperature (° C.)	17 – 41
Ammonia Nitrogen (as NH_3)	nil – 35.0
Nitrate Nitrogen (as NO_3)	nil – 40.0
Organic Nitrogen (as N)	9.8 – 194.0

---

*Except pH and temperature

It is seen that the wastewater temperature and pH did not vary appreciably due to consistent operation of the paper mill process (see Table A-2 in the Appendix). In addition, there were no reported incidents during the study of accidental spills which could have upset the pH. Nitrogen levels were more than sufficient to satisfy nutrient requirements.

Color data from laboratory studies indicated the raw NSSC waste had a color of 24,000 APHA units. At this color level, the waste was very dark brown and extremely turbid.

TABLE 4

COMPARISON OF HYDRAULIC AND PROCESS LOADINGS

Hydraulic Loading Percent of Total		Process Loading Percent of Total	
NSSC Wastewater	Clarified Domestic Wastewater	NSSC Wastewater	Clarified Domestic Wastewater
1	99	12	88
10	90	42	58
50	50	93	7
75	25	98	2
90	10	99+	<1

In summary, wastewater characterization indicated relatively high concentrations of volatile suspended solids, BOD and COD, and showed an adequate amount of phosphorus and nitrogen nutrients for biological treatment. The pH was within limits for biological treatment (6 to 9), but the color was very dark.

SECTION VII

PRIMARY TREATMENT OF NSSC WASTEWATER

The primary treatment of the raw NSSC wastewater was accomplished by settling the pulp and paper solids and removing the sludge from the primary clarifier. The unit was operated throughout most of the study from February, 1971, to March, 1972, and its performance was based upon an evaluation of some of the operational data described in the following subsections.

Operation

The raw NSSC wastewater flowed from the influent weir box by gravity through a four-inch cast iron pipe. The flow depended upon the pilot unit's requirements and was controlled by a throttling valve. Sludge was collected by rakes in the hopper bottom clarifier, and it was withdrawn periodically through an eight-inch pipe at the bottom of the clarifier to the waste sump. At times during the study, heavy fiber paper solids created plugging problems and caused some solids carry-over in the final effluent.

Normally, the raw NSSC wastewater had high concentrations of suspended paper solids (350 to 4,500 mg/l). In addition, there were considerable amounts of unsettleable dissolved and suspended volatile solids which contributed to the total BOD and COD of the wastewater. The temperatures were usually higher than the domestic wastewater and did not fluctuate significantly with ambient temperature changes. This was due to the constant operation of the pulp and paper mill and as a result, temperature was not a major consideration in evaluating the efficiency of the clarifier.

Grab samples were collected at the sample points shown in Table 1 and Figure 2. An evaluation of the data from the influent sample point from May, 1971, through September, 1971, resulted in a change in location of that sample collection station. For that time period, the samples were collected at a location which gave erroneously high suspended solids results. To remedy this, the sampler was changed to a more suitable location for the balance of the study.

Performance

Performance of the primary clarifier was based upon the removal of BOD, COD and VSS at various overflow rates, detention times and solids loading rates. The primary settling data are averaged and summarized in Table 5; the individual data are given in Tables A-2 and A-3 of the Appendix.

TABLE 5

PRIMARY TREATMENT DATA – NSSC WASTE MONTHLY AVERAGES*

Month	Flow (GPD)	Influent Volatile Suspended Solids (mg/l)	Influent BOD (mg/l)	Influent COD (mg/l)	Water Temperature (°F.)	Volatile Suspended Solids	Percent Removal[1] by Sedimentation		Sedimentation		
							BOD	COD	Detention Time (hr)	Overflow Rate (GPSFPD)	Solids Loading (lb/sq ft)
October	22,000	1,370	1,620	9,145,	92	62	-17	8	7.0	254	3
November	16,600	925	1,945	9,320	81	50	-10	10	9.5	192	2
December	28,600	1,385	2,050	8,510	79	45	0	-5	5.3	330	4
January	26,500	665	1,890	7,240	66	76	-21	-15	5.9	306	2
February	23,400	865	1,825	8,660	73	70	-10	13	6.4	270	2
March	17,400	440	1,635	7,140	80	69	-9	13	6.6	201	1
Average	22,400	940	1,825	8,335	79	62	-11	4	6.8	254	2

April and May data omitted due to plant start up
June to October data omitted due to change in sampling procedure
[1] Negative values indicate increases in BOD and COD concentrations due to sedimentation

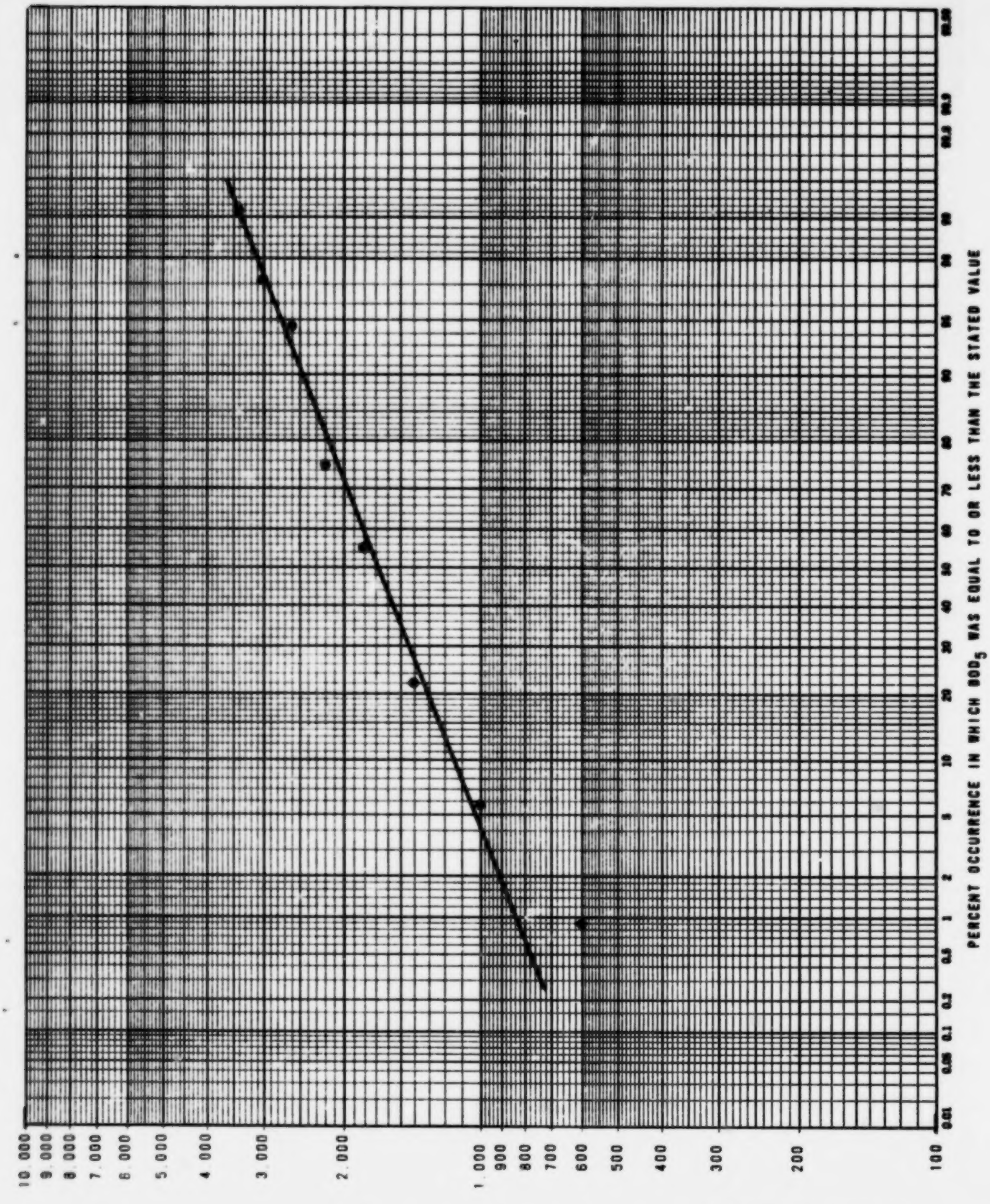
The detention time and overflow rate calculations were based on the volume as calculated from the sidewater depth and inside diameter of the clarifier. For example, an inflow of 22,000 gpd is calculated to give 6.5 hours detention time with an overflow rate of 254 gpd/sq ft. The corresponding weir overflow is 67 gpd/lin ft.

Evaluations based upon statistical analyses before and after clarification are shown graphically in Figures 12, 14, 16 and 17. For BOD and VSS analyses of the influent and effluent, the average values were determined as follows:

Parameter	Geometric Mean (mg/l) Influent	Effluent	Percent Removed
BOD	1,950	1,700	13
VSS	800	450	44

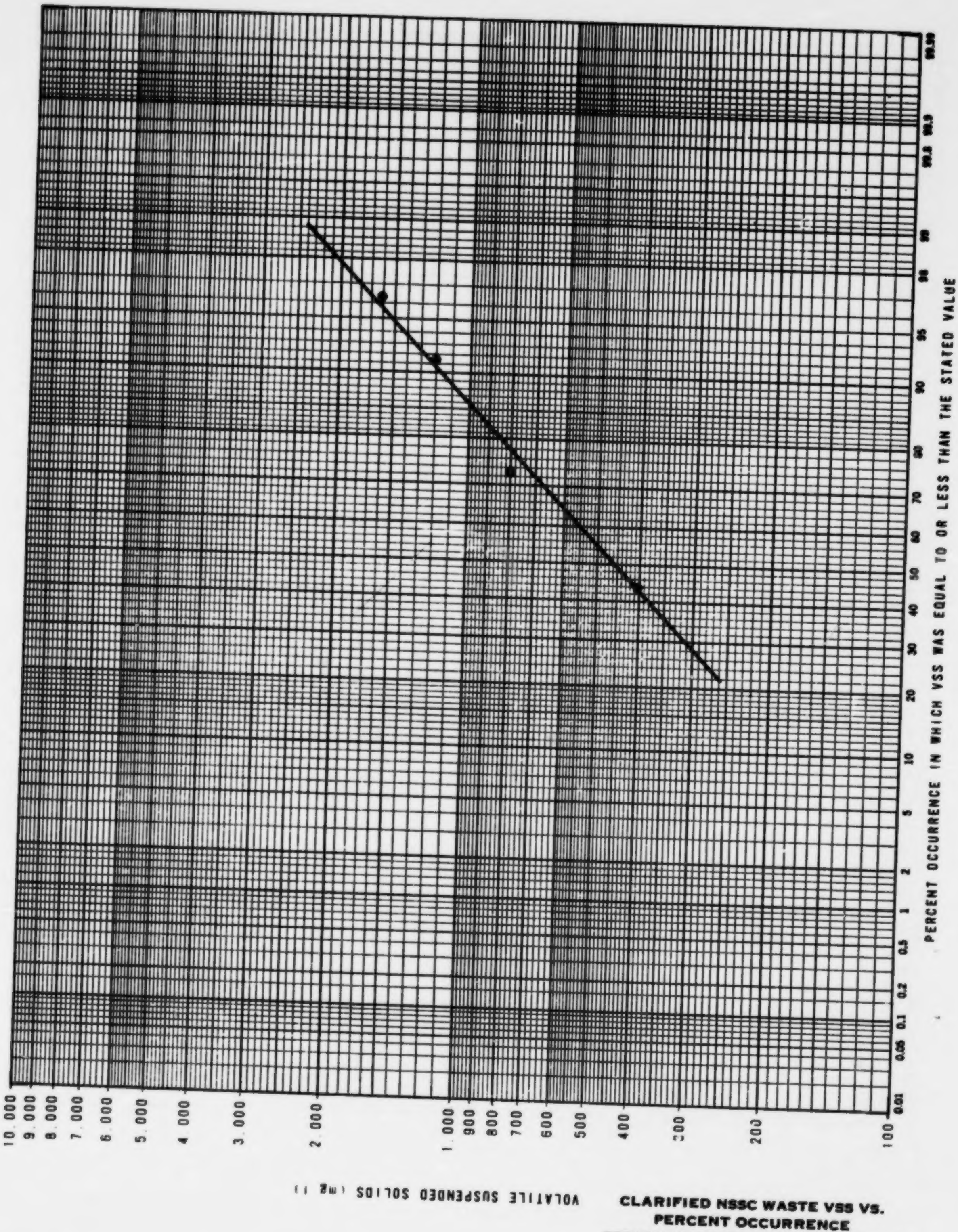
A comparison based upon monthly average calculations (see Table 5) showed reductions of 62 percent for volatile suspended solids and an increase in BOD across the primary clarifier. The COD was reduced an average of four percent and showed some decrease in organics.

The performance evaluations were difficult to determine due to variations in the data for the different detention times and overflow rates. Inconsistent data were due partially to solids overflow when the sludge drawoff line was plugged by paper fibers. Also, variations in performance were caused by the high percentages of unsettleable solids which contributed to the BOD and COD. The volatile suspended solids were reduced an average of 44 to 62 percent for the detention times and overflow rates tested.



CLARIFIED NSSC WASTE BOD$_5$
VS. PERCENT OCCURRENCE
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

FIGURE 16



CLARIFIED NSSC WASTE VSS VS. PERCENT OCCURRENCE

TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES

FIGURE 17

SECTION VIII

BIOFILTRATION

The biofiltration process unit included a high rate trickling filter packed with synthetic media and an intermediate clarifier with recirculation. This unit was operated from October, 1971, through March, 1972. The performance was rated according to data collected from a sampling program during this period.

Operation

For the first six to eight weeks of operation the biofilter developed a growth and was allowed to acclimate to the wastewater. Samples were collected from sample points as indicated in Table 1 and Figure 2. Only the data collected after the first six weeks of operation was used in the performance evaluation. During the study the NSSC wastewater percentage ranged from 70 to 100 percent. At the times when 100 percent NSSC wastewater was used some tap water was introduced to assure proper operation of the trickling filter distribution arm.

Performance

Table 6 provides weekly average operating data for the biofiltration process. Of particular importance is the data on process loading. A comparison of normal high rate filter loading and that experienced by the biofilter in this study is as follows:

Biofilter Description	Hydraulic Loading (mgd/acre)	Organic Loading (lb BOD/1,000 CF)
Normal High Rate Biofilter	10 – 30	80 – 100
Pilot Plant Biofilter	48 – 102	100 – 400

The data in Table 6 also shows the rather narrow temperature range the biofilter encountered. For the period of data evaluation, the high temperature was 20° C. with an average of 16° C. Due to the relatively narrow temperature range, the standard temperature correction factor (Eckenfelder, 1966) for biofilters was not applied.

The BOD organic loading (pounds per day per thousand cubic feet filter media) was plotted versus the BOD removed (ppd) as shown in Figure 18. This figure shows clearly that primary treatment of the raw NSSC waste improved the BOD removal efficiency. As an example,

TABLE 6

BIOFILTER OPERATION DATA WITH PRIMARY TREATMENT

Week of	Temperature		Process Loading (lb/day/1,000 ft^3)		Hydraulic Loading with Recirc. (mdg/acre)	Recirc. Rate (percent)	Removal (percent)		Removal (lb per day)		NSSC Content of Combined BOD (percent)
	°F.	°C.	BOD	COD			BOD	COD	BOD	COD	
10/10[1]	–	–	290[2]	–	74	50	27[2]	–	115[2]	–	70
10/17[1]	79	26	360	1,740	84	50	11	25	60	640	66
10/24[1]	77	25	370	1,190	74	60	17	17	95	300	73
10/31[1]	73	23	200	690	64	90	14	11	40	120	83
11/7[1]	66	19	200	1,050	58	130	10	36	30	550	72
11/14	72	22	180	680[2]	47	140	18	17[2]	45	170[2]	69
11/21	66	19	465[2]	1,340[2]	108	150	45[2]	8[2]	310[2]	150[2]	66
11/28	64	18	420	1,680	108	50	17	25	130	620	76
12/5	66	19	325	1,250	85	60	28	60	135	1,090	82
12/12	68	20	450	1,460[2]	106	35	18	28[2]	120	590[2]	83
12/19	66	19	375	1,110	100	50	3	2	20	40	80
12/26	66	19	435[2]	1,470[2]	101	60	24[2]	24[2]	150[2]	510[2]	74
1/2	55	13	510	1,480	98	60	3	4	25	100	90
1/9	68	20	505	1,240	82	40	16	10	95	190	83
1/16	63	17	390	1,190	99	60	8	–	45	–	81
1/23	59	15	95	335	76	90	18	12[2]	25	60[2]	89
1/30	52	11	120	305	85	100	9	1	15	5	96
2/6	54	12	115	345	84	110	18	7	30	35	97
2/13	54	12	90	300	64	120	11	13	15	55	100
2/20	54	12	100	345	64	130	14	12	20	60	100
2/27	59	15	75	230	57	95	–	–	–	–	100
Average	62	16	291	923	82	80	16	14	74	330	82
WITHOUT PRIMARY TREATMENT											
3/15	57	14	275	890	89	50	9	13	35	270	80
3/12	63	17	255	990	106	50	18	19	70	310	71
3/19	63	17	230	1,030	90	65	15	32	50	490	77
3/26	63	17	280	890	89	65	11	14	45	190	90
Average	62	16	260	950	93	60	13	20	50	315	79

[1] Period allowed for biofilter start up; data not used in evaluation

[2] Based on a single day's data

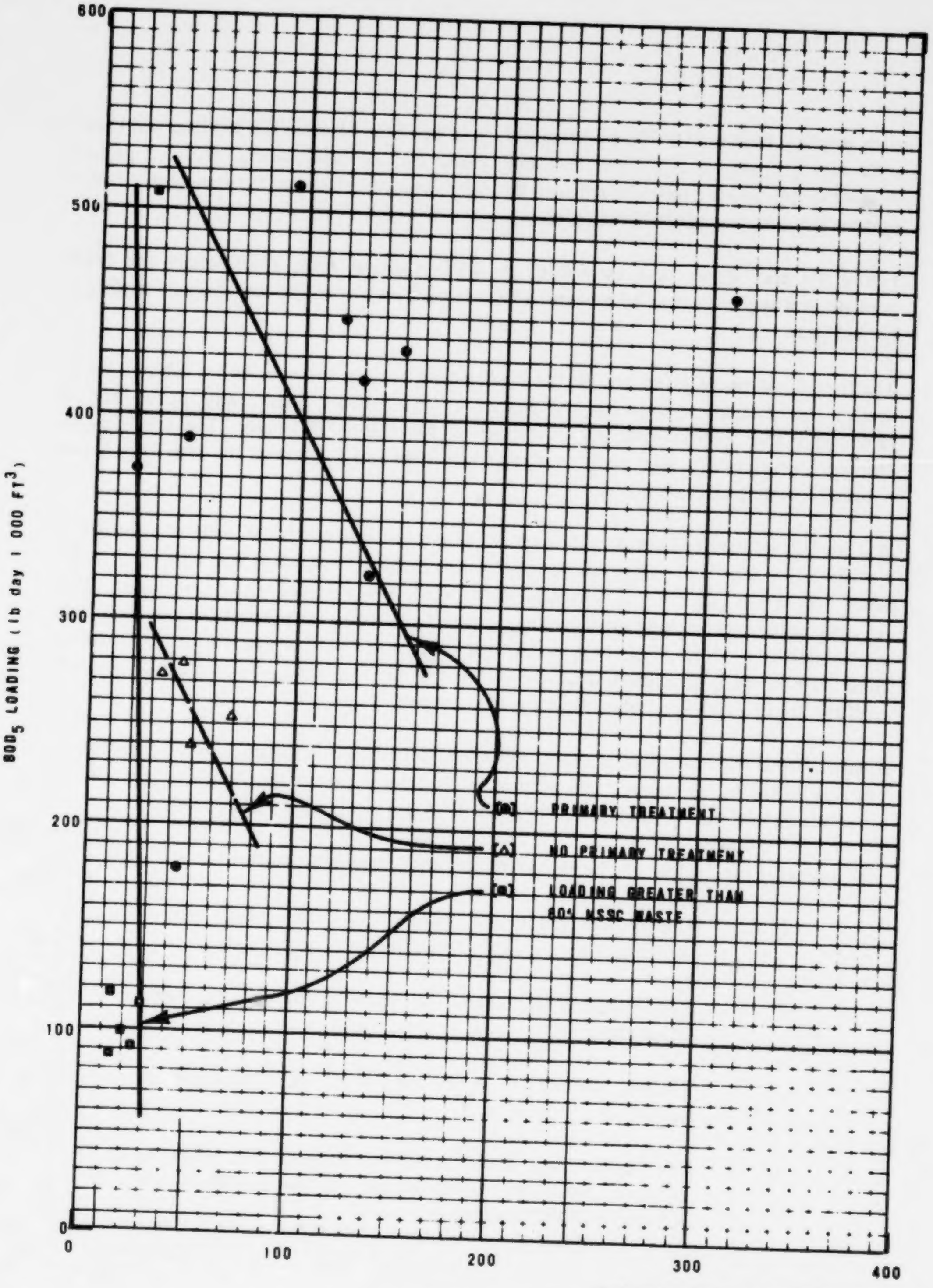
TABLE 6

BIOFILTER OPERATION DATA WITH PRIMARY TREATMENT

	Temperature		Process Loading (lb/day/1,000 ft^3)		Hydraulic Loading with Recirc.	Recirc. Rate	Removal (percent)		Removal (lb per day)		NSSC Content of Combined BOD
Week of	°F.	°C.	BOD	COD	(mdg/acre)	(percent)	BOD	COD	BOD	COD	(percent)
10/10[1]	–	–	290[2]	–	74	50	27[2]	–	115[2]	–	70
10/17[1]	79	26	360	1,740	84	50	11	25	60	640	66
10/24[1]	77	25	370	1,190	74	60	17	17	95	300	73
10/31[1]	73	23	200	690	64	90	14	11	40	120	83
11/7[1]	66	19	200	1,050	58	150	10	36	30	550	72
11/14	72	22	180	680[2]	47	140	18	17[2]	45	170[2]	69
11/21	66	19	465[2]	1,340[2]	108	150	45[2]	8[2]	310[2]	150[2]	66
11/28	64	18	420	1,680	108	50	17	25	130	620	76
12/5	66	19	325	1,250	85	60	28	60	135	1,090	82
12/12	68	20	450	1,460[2]	106	35	18	28[2]	120	590[2]	83
12/19	66	19	375	1,110	100	50	3	2	20	40	80
12/26	66	19	435[2]	1,470[2]	101	60	24[2]	24[2]	150[2]	510[2]	74
1/2	55	13	510	1,480	98	60	3	4	25	100	90
1/9	68	20	505	1,240	82	40	16	10	95	190	83
1/16	63	17	390	1,190	99	60	8	–	45	–	81
1/23	59	15	95	335	76	90	18	12[2]	25	60[2]	89
1/30	52	11	120	305	85	100	9	1	15	5	96
2/6	54	12	115	345	84	110	18	7	30	35	97
2/13	54	12	90	300	64	120	11	13	15	55	100
2/20	54	12	100	345	64	130	14	12	20	60	100
2/27	59	15	75	230	57	95	–	–	–	–	100
Average	62	16	291	923	82	80	16	14	74	330	82
WITHOUT PRIMARY TREATMENT											
3/15	57	14	275	890	89	50	9	13	35	270	80
3/12	63	17	255	990	106	50	18	19	70	310	71
3/19	63	17	230	1,030	90	65	15	32	50	490	77
3/26	63	17	280	890	89	65	11	14	45	190	90
Average	62	16	260	950	93	60	13	20	50	315	79

[1] Period allowed for biofilter start up; data not used in evaluation

[2] Based on a single day's data



BIO-FILTRATION BOD_5 REMOVAL VS. BOD_5 LOADING
TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES

FIGURE 18

with primary treatment a 100 ppd removal could be achieved when the biofilter was loaded with 400 pounds of BOD per thousand cubic feet of filter media. Without primary treatment, the loading must be reduced to 160 pounds of BOD per thousand cubic feet to achieve the same pounds BOD removed.

Figure 18 also shows that essentially no BOD removal took place where the NSSC percentage was greater than 80 percent. This was independent of the total organic loading to the biofilter.

The overall treatment efficiency of the biofiltration process can be seen in Table 6. On an average the biofilter removed only 16 percent and 13 percent, respectively, of the influent BOD with and without primary treatment of the raw NSSC waste. The low removal efficiency (typical of a high rate "roughing" biofilter) was a result of the high organic and hydraulic loading of the biofilter.

William Eckenfelder's, *Manual of Treatment Processes*, cited hydraulic loadings of biofilters treating other pulp and paper mill process wastes ranging from 90 to 365 mgd/acre for the Kraft Mill waste and 47 to 189 mgd/acre for black liquor wastes with no recycling. BOD removal rates at those hydraulic loadings ranged from 10 to 31 percent for the Kraft Mill wastes and from 58 to 73 percent for the black liquor wastes. The raw wastes in the studies cited were diluted, as witnessed by the influent BOD concentration of 250 mg/l and 400 mg/l for the Kraft Mill and black liquor wastes, respectively.

Design criteria for operation of the biofiltration process can be taken directly from Figure 18. For example, to remove 100 pounds of BOD per day by biofiltration, it would be necessary to load the biofilter at 400 ppd per thousand cubic feet of filter media.

The following conclusions can be made from the biofiltration evaluation:

1. The biofilter functioned primarily as a "roughing" filter at the high hydraulic and organic loadings experienced.
2. The "roughing" filter function improved downstream process efficiencies.
3. Primary clarification of the raw NSSC waste improved the biofiltration efficiency.
4. The biofilter was not effective in removing BOD from the combined wastewater with high percentages (greater than 80 percent) of NSSC wastewater.

SECTION IX

EXTENDED AERATION TREATMENT

The extended aeration system of the pilot plant was comprised of an aeration basin with diffused air and a final clarifier with sludge return. Operation of the system began in February, 1971, and continued through March, 1972. The performance of the system was evaluated by collecting data based upon a sampling and analytical program carried out during the study. Variations in NSSC to domestic waste loading, hydraulic flows, aeration detention times, temperature, primary treatment, etc., were achieved during the study. The effects of these conditions on the extended aeration process were evaluated from an operation and performance standpoint.

Extended aeration was studied in three different arrangements:

Arrangement No. 1	Pretreatment with primary clarification
Arrangement No. 3	Pretreatment with primary clarification and biofiltration
Arrangement No. 4	Pretreatment by biofiltration

Finally, performance comparisons of each of the three arrangements were made; oxygen data and sludge production design criteria were developed.

Extended Aeration with Primary Clarification – Arrangement No. 1

The aeration basin was operated with primary clarification from July, 1971, through September, 1971. During this period, the percentage of the wastewater loading which was NSSC BOD loading ranged from 42 to 100 percent. In addition, attempts were made to optimize the mixed liquor volatile suspended solids (MLVSS) at various flows and BOD loadings. Since BOD loadings could not be determined immediately, flow control was the primary means of varying the loadings.

Evaluation of the extended aeration process with primary clarification was based upon the results summarized in Table 7. A comparison of BOD loading to effluent quality is given in Figure 19. As can to be from this graph, there appeared to be no significant difference in the effluent quality for the various percentages of the NSSC wastewater evaluated. It is believed that the NSSC loadings (which were always greater than 42 percent of the wastewater) were too high to provide a significant comparison of variation in efficiencies of extended aeration with NSSC and domestic wastewater influents.

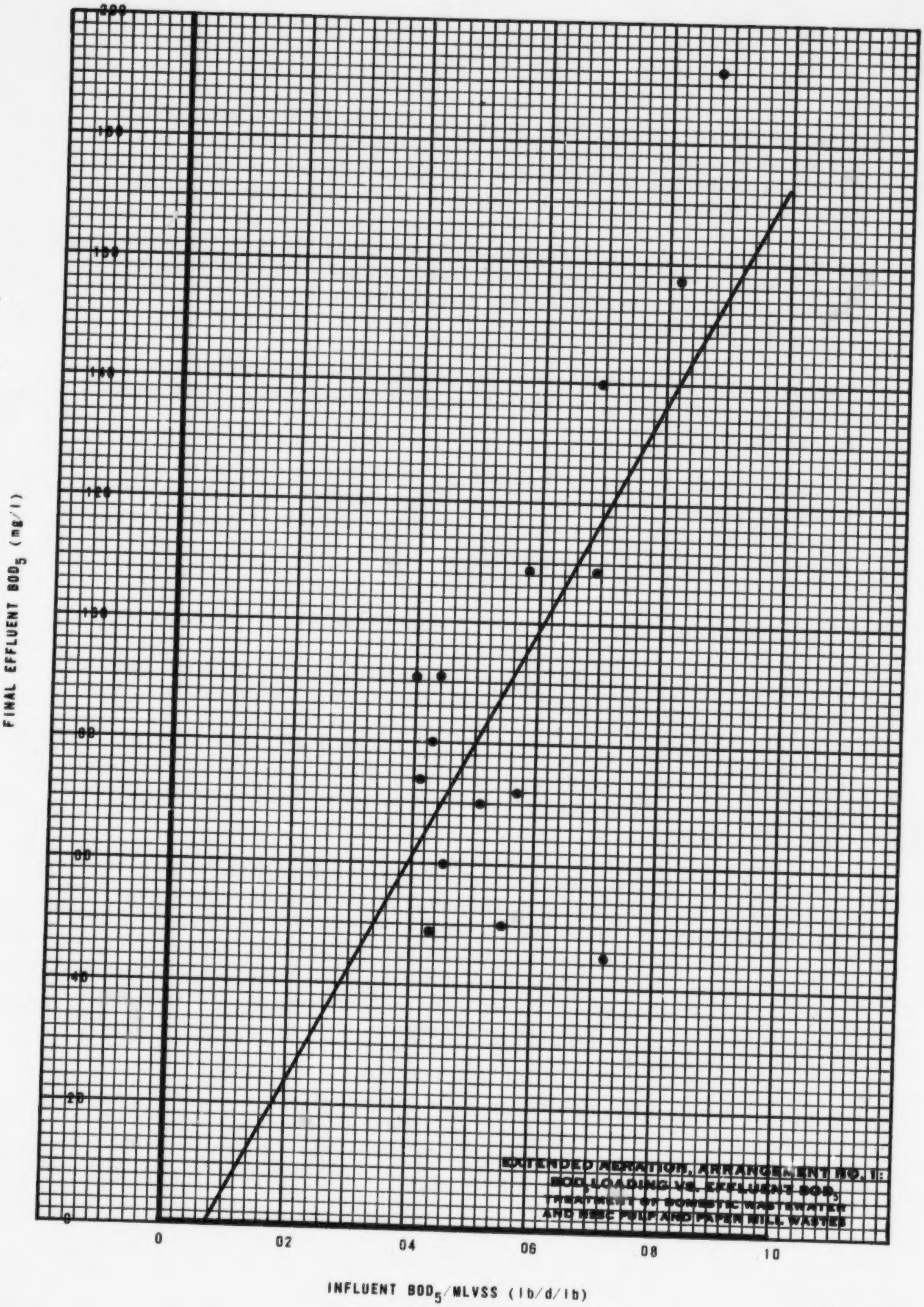
TABLE 7

EXTENDED AERATION RESULTS – (JULY 14 - AUGUST 26, 1971)

ARRANGEMENT NO. 1

Date	Operating Temperature (°C.)	MLVSS (mg/l)	Percent NSSC Waste Based on BOD	Oxygen Transferred* (lb per day)	BOD Removed		Influent BOD/MLVSS (lb/day/lb)	BOD		Excess Sludge (lb/mgd)	Influent VSS (lb/mgd)
					(lb per day)	(lb/mgd)		Percent Removed	Effluent (mg/l)		
7/14/71	–	–	–	–	–	–	–	–	–	1,018	3,333
20	27	3,590	100	33	120	–	0.043	76	51	–	–
21	28	3,960	100	450	1,67	1,422	0.069	61	108	4,114	5,256
22	28	3,980	96	467	137	1,297	0.058	60	108	1,402	4,337
27	29	3,810	93	480	177	–	0.088	53	191	–	–
28	29	3,290	94	529	142	–	0.082	52	157	–	–
29	29	4,120	83	494	166	–	0.070	58	140	–	–
8/10/71	29	2,950	100	562	170	–	0.071	82	45	–	–
11	29	3,170	96	583	131	1,345	0.055	76	52	1,386	–
12	28	3,460	100	625	83	871	0.041	59	74	6,296	2,581
17	28	3,500	60	591	142	–	0.057	71	72	–	–
18	28	3,550	95	580	92	1,024	0.043	60	83	1,336	3,586
19	29	3,950	93	562	134	1,492	0.045	75	60	4,822	–
24	29	3,380	73	556	121	–	0.051	71	67	–	–
25	28	3,380	100	517	67	–	0.040	50	90	–	–
26	28	3,440	100	503	85	932	0.044	55	91	1,941	3,673

*Standard conditions, 5.5 percent transfer efficiency



EXTENDED AERATION, ARRANGEMENT NO. 1:
BOD_5 LOADING VS. EFFLUENT BOD_5
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

FIGURE 19

Primary clarification efficiency had a measurable effect on the extended aeration basin process loading versus BOD effluent quality. Prior to entering the aeration basin the VSS of the clarified and blended wastewater varied from 300 to 410 pounds per day for the flows measured. At these loadings the VSS averaged 0.1 pounds per pound of MLVSS. Without primary clarification the ratio of VSS of the blended wastewater would be as high as 0.2 pounds per pound of MLVSS. As the ratio of blended influent VSS to MLVSS increased, a poorer effluent quality for a given process loading resulted. This indicates the relative importance of removing the inert volatile suspended matter from the waste prior to its entering the aeration basin.

The design criteria for the aeration basin may be derived from the graph in Figure 19. For example, an effluent BOD of 60 mg/l will require an influent loading of 0.04 pounds of BOD per pound of MLVSS.

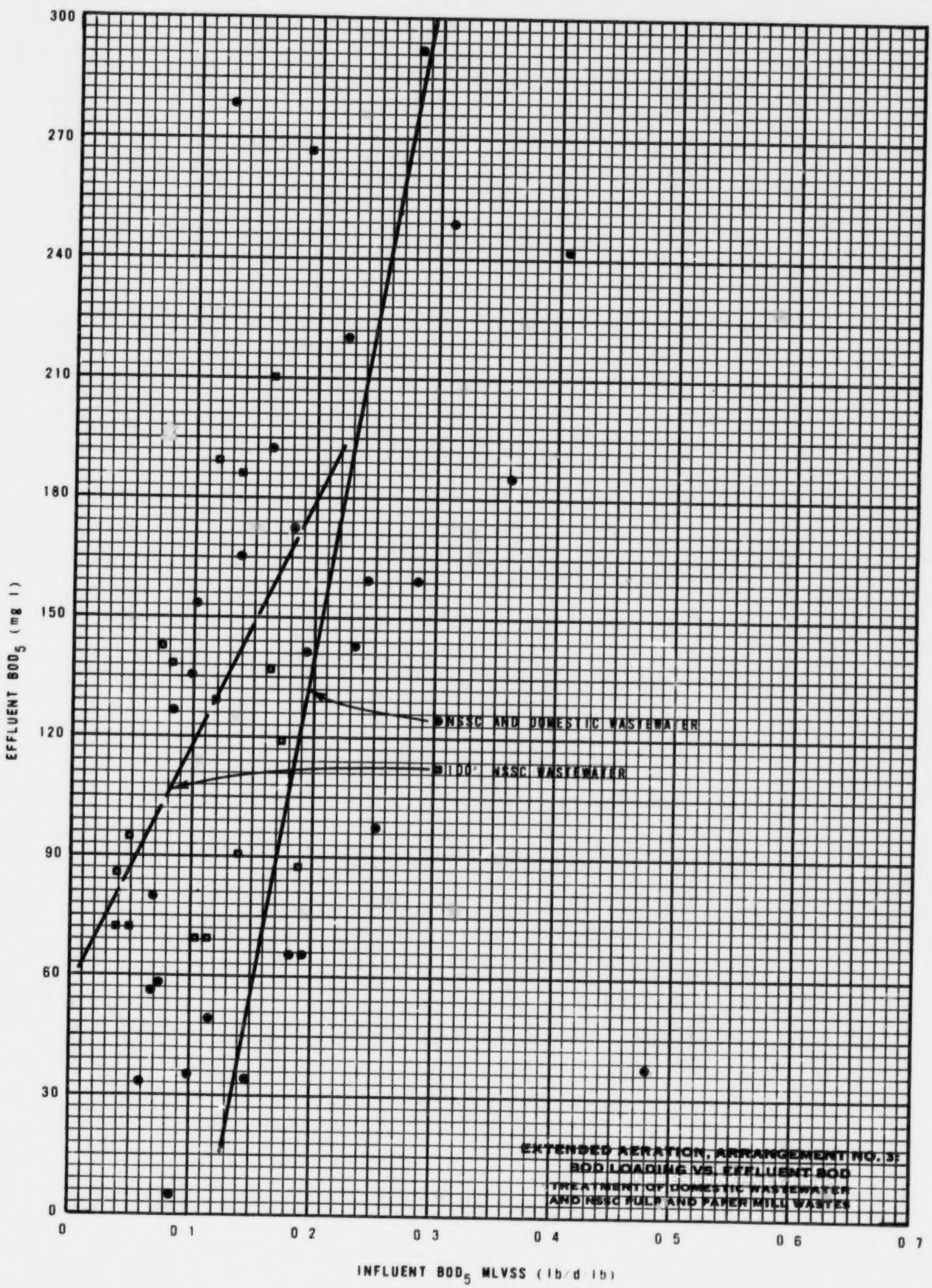
In Arrangement No. 1, it was found that with the process loadings evaluated there was little measurable difference in efficiency due to changes in NSSC wastewater percentages. Removal of VSS in the primary clarifier provided improved effluent quality at the same BOD to MLVSS loading.

Extended Aeration with Primary Clarification and Biofiltration – Arrangement No. 3

The aeration basin was operated with primary clarification of the raw NSSC waste and biofiltration of the blended NSSC-domestic wastewater from October, 1971, to March, 1972. The percentage of NSSC wastewater loading ranged from 44 to 100 percent using Arrangement No. 3. The hydraulic loadings to the biofilter were varied by changing the recirculation ratio, and normally these rates exceeded 40 mgd/acre. In order to maintain sufficient flow to rotate the trickling filter arm (at 100 percent NSSC wastewater) tap water was added to the NSSC waste.

The performance of the extended aeration basin under different ratios of NSSC to domestic wastewater is illustrated by Figure 20. The performance of this process is based upon results summarized in Table 8. At the range of process loadings tested, it is seen that a poorer quality effluent resulted with the 100 percent NSSC wastewater at a given loading. For example, a process loading of 0.15 pounds of BOD per pound of MLVSS would result in an effluent BOD of approximately 150 mg/l. On the other hand, the same process loading (0.15 lb BOD/lb MLVSS) would give an effluent BOD of 50 mg/l in the case of a blended NSSC-domestic waste.

The design criteria for the aeration basin under Arrangement No. 3 may be derived from the graph in Figure 21. For example, an effluent BOD of 60 mg/l will require an influent loading of 0.001 pounds of BOD per pound of MLVSS for the 100 percent NSSC wastewater and 0.16 pounds of BOD per pound of MLVSS for the blended NSSC and domestic wastewater.



EXTENDED AERATION, ARRANGEMENT NO. 3:
BOD LOADING VS. EFFLUENT BOD
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

FIGURE 20

TABLE 8

EXTENDED AERATION RESULTS – (OCTOBER 13, 1971 – MARCH 2, 1972)

ARRANGEMENT NO. 3

Date	Operating Temperature (°C.)	MLVSS (mg/l)	Percent NSSC Waste Based on BOD	Oxygen Transferred* (lb per day)	BOD Removed (lb per day)	BOD Removed (lb/mgd)	Influent BOD/MLVSS (lb/day/lb)	BOD Percent Removed	BOD Effluent (mg/l)	Excess Sludge (lb/mgd)	Influent VSS (lb/mgd)
10/13/71	23	2,240	–	425	334	–	0.183	81	65	–	–
14	25	2,940	–	405	299	–	0.118	86	49	–	–
20	26	3,280	97	527	284	–	0.139	62	165	–	–
21	26	2,960	63	556	303	–	0.166	62	192	–	–
26	24	3,110	72	488	315	–	0.126	80	87	–	–
27	24	3,240	47	483	398	3,557	0.153	80	104	2,279	4,004
28	26	3,200	100	546	344	3,254	0.135	79	101	407	2,583
11/2/71	25	2,840	67	508	142	–	0.071	70	79	–	–
3	23	3,160	79	552	288	3,107	0.100	91	35	4,423	3,506
4	20	3,420	79	564	194	2,093	0.069	82	56	3,927	1,920
9	16	4,000	82	421	221	–	0.061	90	33	–	–
10	17	3,760	96	376	241	–	0.075	86	58	–	–
16	21	1,920	96	473	165	–	0.088	98	5	–	–
23	16	2,520	57	423	330	–	0.149	88	34	–	–
30	16	2,780	91	–	361	–	0.195	66	141	–	–
12/1/71	17	2,940	44	519	508	–	0.238	73	143	–	–
7	18	1,350	87	299	198	–	0.193	76	65	–	–
8	18	1,400	60	302	304	2,272	0.364	60	185	1,166	4,589
14	19	2,640	83	341	276	–	0.186	56	172	–	–
15	21	2,400	97	358	378	2,397	0.245	64	159	184	2,505
21	19	1,780	92	392	334	–	0.253	74	97	–	–
22	17	2,160	100	354	420	2,800	0.287	68	159	3,653	6,173
28	17	1,000	58	–	435	–	0.481	90	37	–	–

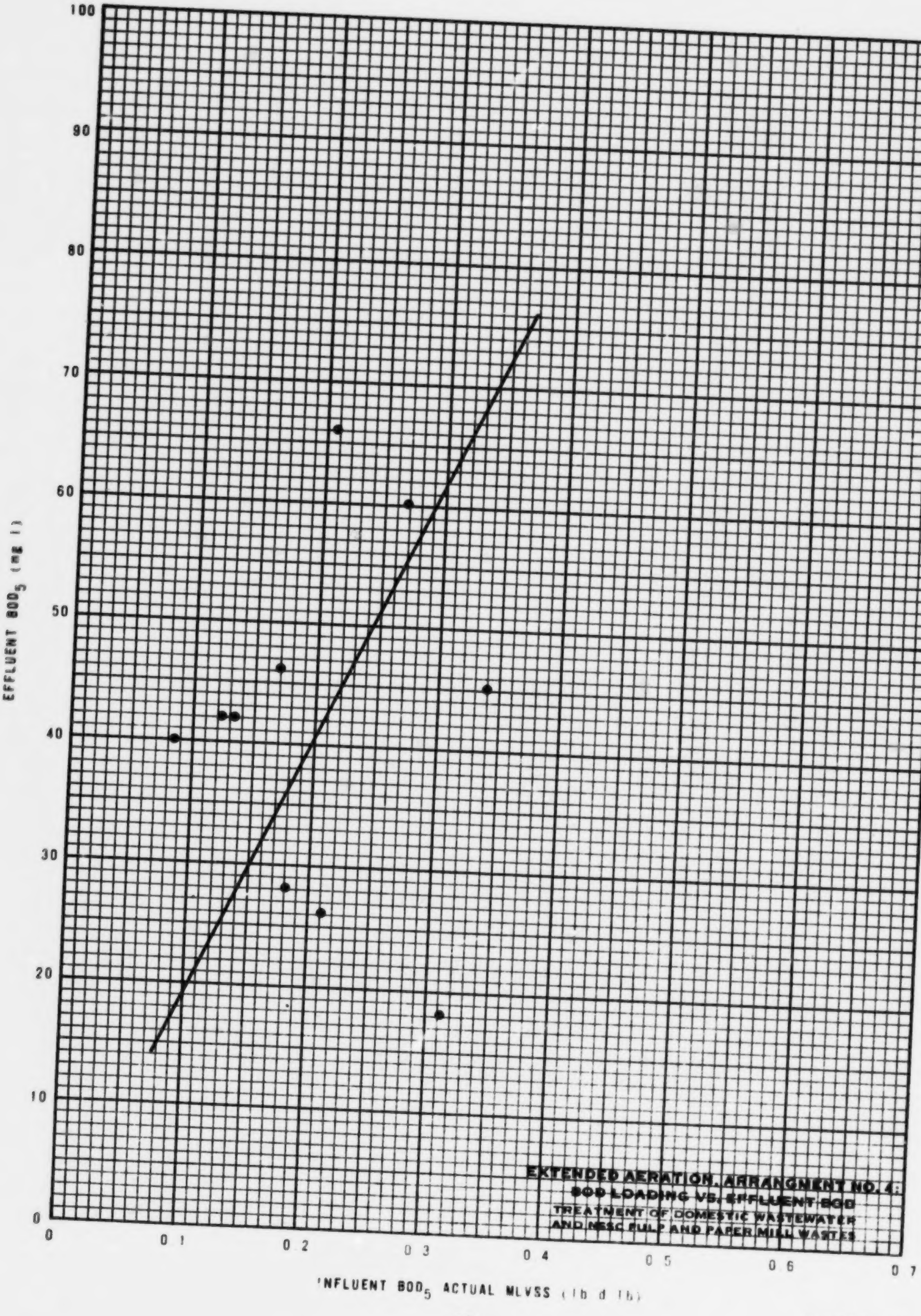
TABLE 8 (Continued)

EXTENDED AERATION RESULTS – (OCTOBER 13, 1971 – MARCH 2, 1972)

ARRANGEMENT NO. 3

Date	Operating Temperature (°C.)	MLVSS (mg/l)	Percent NSSC Waste Based on BOD	Oxygen Transferred* (lb per day)	BOD Removed (lb per day)	BOD Removed (lb/mgd)	Influent BOD/MLVSS (lb/day/lb)	BOD Percent Removed	BOD Effluent (mg/l)	Excess Sludge (lb/mgd)	Influent VSS (lb/mgd)
1/4/72	16	940	73	–	544	–	0.837	69	200	–	–
11	18	1,880	52	235	201	–	0.286	37	293	–	–
12	17	800	100	–	108	–	0.412	33	242	–	–
13	19	1,660	100	177	292	–	0.313	56	248	–	–
19	16	2,360	79	315	260	1,736	0.227	49	220	–	–
20	17	2,940	100	222	104	780	0.140	24	279	280	–
25	15	2,960	100	–	71	–	0.037	65	73	1,724	–
26	16	2,720	67	–	60	–	0.031	72	73	–	–
27	12	2,100	99	–	109	–	0.063	82	69	–	–
2/1/72	12	2,300	54	–	119	–	0.061	85	69	–	–
2	11	1,820	56	–	109	–	0.074	81	91	–	–
3	11	2,220	89	–	165	1,337	0.092	81	119	4,198	997
8	13	1,260	90	–	87	–	0.099	69	137	–	–
9	12	1,620	72	–	86	608	0.093	57	211	3,336	1,668
10	13	1,160	83	–	55	–	0.117	41	267	–	–
15	12	2,740	64	–	92	–	0.043	77	143	–	–
16	12	2,200	61	–	122	–	0.068	82	129	–	–
17	12	2,980	98	–	65	689	0.028	77	95	8,388	1,750
22	12	2,580	61	–	93	–	0.047	76	138	–	–
23	11	2,060	85	–	92	–	0.064	70	189	–	–
29	15	1,740	75	–	134	–	0.097	79	187	–	–
3/1/72	15	2,060	100	–	41	486	0.028	72	85	6,505	166
2	16	1,060	66	–	135	–	0.142	89	87	–	–

*Standard conditions, 5.5 percent transfer efficiency



EXTENDED AERATION, ARRANGMENT NO. 4: BOD LOADING VS. EFFLUENT BOD

TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES

FIGURE 21

Extended Aeration with Biofiltration – Arrangement No. 4

The aeration basin was operated with biofiltration of the blended wastewater and unclarified NSSC wastewaters during March, 1972. The percentage of NSSC wastewater loading ranged from 50 percent to 100 percent using Arrangement No. 4. The effluent from the biofilter was clarified in the intermediate clarifier.

Performance of the extended aeration process with biofiltration was based upon the results summarized in Table 9. A comparison of BOD loading to effluent quality is shown in Figure 21. The graph shows no significant difference in effluent quality of the various percentages of the NSSC wastewater evaluated.

The data in Table 9 does show a slightly lower MLVSS than in Arrangements No. 1 or 3. This might, in part, be due to the lower VSS loading (approximately 75 pounds/day VSS) to the aeration basin during Arrangement No. 4.

The design criteria for the aeration basin under Arrangement No. 4 may be derived from Figure 21. For example, an effluent BOD of 60 mg/l will require an influent loading of 0.29 pounds of BOD per pound of MLVSS for the blended domestic and unclarified NSSC wastewaters.

Performance of Arrangements No. 1, No. 3 and No. 4

The relative performance of the extended aeration process following primary clarification, biofiltration and both pretreatment processes, was evaluated. A comparison of the arrangements indicated biofiltration provided the best effluent quality at the highest process loading. The effluent BOD concentration of 60 mg/l was used as a comparison figure which corresponds to approximately 97 percent BOD removal. To achieve the desired end results (60 mg/l BOD) the process loadings would have to be adjusted for each arrangement as shown below:

Arrangement No.	Description	Process Loading (lb BOD/day/lb MLVSS)	Effluent BOD (mg/l)
1	Primary clarification	0.04	60
3	Primary clarification plus biofiltration	0.001 – 0.16	60
4	Biofiltration	0.29	60

In the case of Arrangement No. 3, the lower limit of the loading range (0.001 lb BOD/day/lb MLVSS) provided an effluent of 60 mg/l when the wastewater was 100 percent NSSC waste. Temperature variations (11° – 32° C.) were considered to have negligible effects on the

TABLE 9

EXTENDED AERATION RESULTS – (MARCH 3–29, 1972)

ARRANGEMENT NO. 4

Date	Operating Temperature (°C.)	MLVSS (mg/l)	Percent NSBC Waste Based on BOD	Oxygen Transferred* (lb per day)	BOD Removed (lb per day)	BOD Removed (lb/mgd)	Influent BOD/MLVSS (lb/day/lb)	BOD Percent Removed	BOD Effluent (mg/l)	Excess Sludge (lb/mgd)	Influent VSS (lb/mgd)
3/7/72	14	1,100	60	–	320	–	0.341	85	45	–	–
8	14	1,380	95	–	314	2,549	0.271	84	60	2,565	747
9	13	1,580	100	–	278	2,256	0.219	80	66	1,916	170
14	16	620	86	–	332	–	0.639	84	49	–	–
15	17	2,100	66	–	209	1,356	0.125	80	41	9,565	169
16	18	1,900	78	–	201	–	0.134	79	41	–	–
21	18	1,860	85	–	119	–	0.087	74	40	–	–
22	17	1,080	77	–	316	–	0.311	94	18	–	–
23	15	1,960	62	275	324	2,490	0.181	91	28	7,725	85
28	18	1,640	75	299	318	–	0.211	92	26	–	–
29	19	2,200	100	331	327	2,513	0.171	87	46	4,512	254

*Standard conditions, 5.5 percent transfer efficiency

aeration process since the BOD loading was maintained well below 0.5 pounds of BOD per pound of MLVSS per day. At higher loadings temperature would have a noticeable influence on the aeration basin effluent quality.

Extended Aeration Oxygen Requirements and Utilization

The oxygenation characteristics of the combined NSSC waste and domestic wastewater vary with the percentage of NSSC waste based on BOD. These oxygenation characteristics were determined for the combined waste with 20 percent and 75 percent NSSC waste.

Alpha (α)

The alpha (α) coefficient was determined for several different percentages of NSSC and domestic wastewater utilizing diffused aeration. The aeration rate was maintained constant for tap water aeration and waste aeration for each "α" value determined.

The alpha (α) values were calculated from the following mathematical derivation:

$$W = \frac{dc}{dt} = K_{La} (C^* - C)$$

Where C = dissolved oxygen concentration at time t
C^* = equilibrium dissolved oxygen concentration
t = time
W = weight of water
K_{La} = overall mass transfer coefficient

The integration of the above equation yields

$$K_{La} = \left(\frac{2.303\ W}{10^6}\right) \left(\frac{\log \dfrac{C^* - C_1}{C^* - C_2}}{t_2 - t_1}\right)$$

where subscripts 1 and 2 refer to measurements at times 1 and 2, respectively.

Since the sample volume was identical for both the tap water and the waste samples, these expressions of K_{La} may be simplified to

$$K_{La} = (K) \left(\frac{\log \dfrac{C^* - C_1}{C^* - C_2}}{t_2 - t_1}\right)$$

The above equation may be solved graphically by plotting (C* - C) versus time on semi-logarithmic paper and determining the time interval for one cycle.

$$K_{La} = (K) \frac{\log 10}{t_2 - t_1}$$

thence

$$\text{alpha } (\alpha) = \frac{K_{La}\text{ (waste)}}{K_{La}\text{ (tap water)}} = \frac{K\left(\frac{\log 10}{t_2 - t_1}\right)\text{wastes}}{K\left(\frac{\log 10}{t_2 - t_1}\right)\text{tap water}}$$

The oxygenation data was evaluated and alpha (α) values for various percentages of NSSC wastes were determined. Table 10 correlates the alpha (α) values determined versus the NSSC percentage of that waste. Figure 22 shows the correlation of alpha (α) versus various NSSC percentages of the combined waste.

Beta (β)

The beta (β) factor expresses the ratio of the saturation of dissolved oxygen in a waste to saturation in tap water at given conditions.

The saturation of oxygen in combined NSSC-domestic wastewater was found to vary with the percentage of NSSC waste. The correlation of beta (β) to the percentage of NSSC waste is shown in Table 10 and in Figure 22. Figure 22 shows that for several percentages of NSSC waste evaluated, both alpha and beta decreased with increasing NSSC percentages of the wastewater.

Oxygen Utilization

The air applied, temperature and dissolved oxygen of the mixed liquor in the aeration basin were monitored daily. These data, as well as the alpha (α) and beta (β) values, were utilized to evaluate the oxygen requirements of the extended aeration process. All data were corrected to standard conditions for interpretation. The oxygenation data, given in Table 11, were adjusted to an arbitrary MLVSS concentration of 3,000 mg/l to permit correlation of the data. The oxygen applied relative to BOD removed data is shown graphically in Figure 23. The curve of best fit for these data indicates the following oxygen requirement at standard conditions:

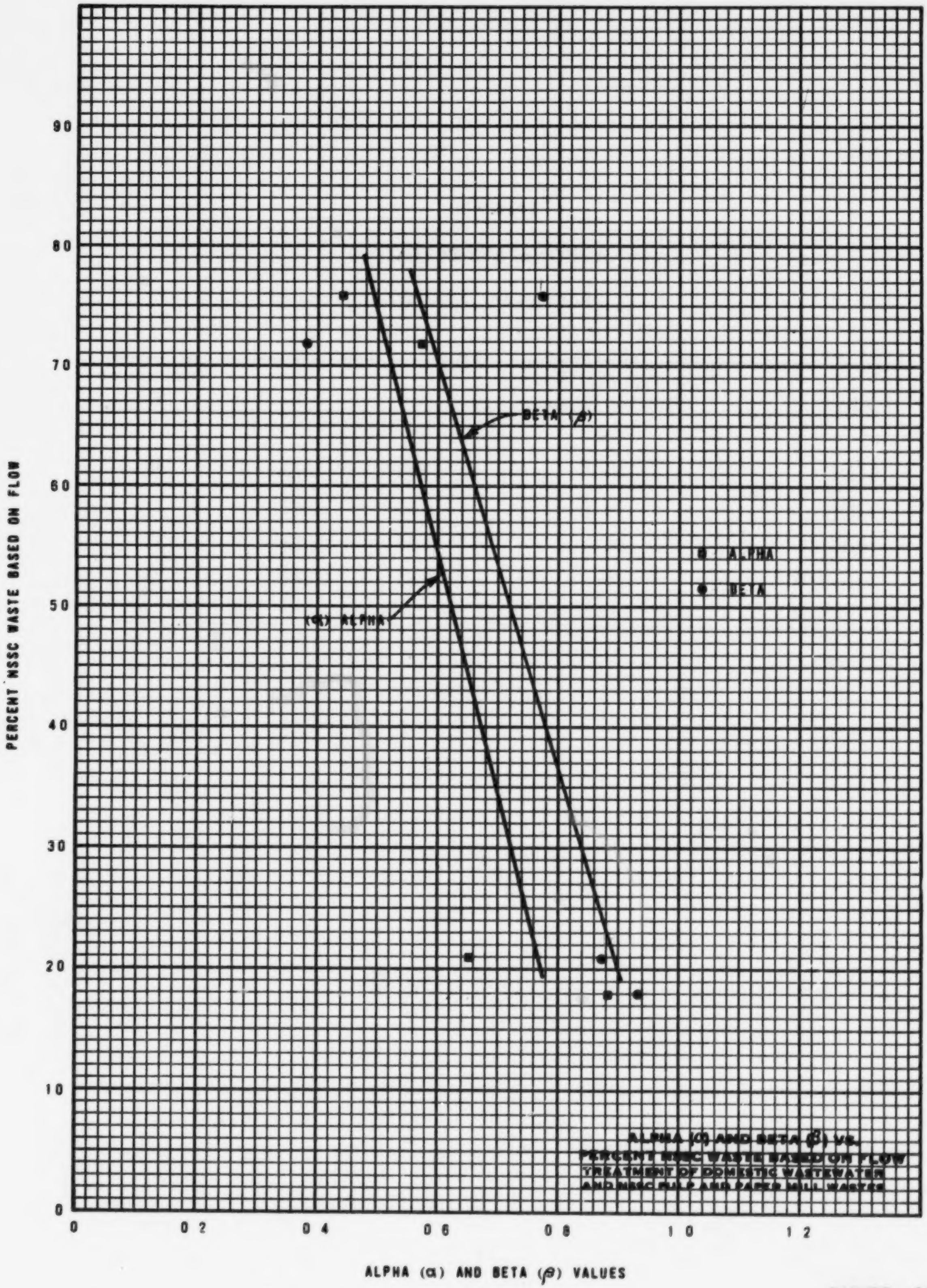
$$\text{Oxygen requirement} = 0.97\text{ BOD removed} + 0.07\text{ MLVSS}$$

TABLE 10

ALPHA (α) AND BETA (β)

VS. PERCENTAGE NSSC WASTE

Date	Percentage NSSC Waste Based on Flow	α	β	Temperature °C.
9/22/71	76	0.42	0.77	29
9/23/71	72	0.57	0.42	31
10/13/71	18	0.88	0.93	31
10/14/71	21	0.65	0.87	23



ALPHA (α) AND BETA (β) VS.
PERCENT NSSC WASTE BASED ON FLOW
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

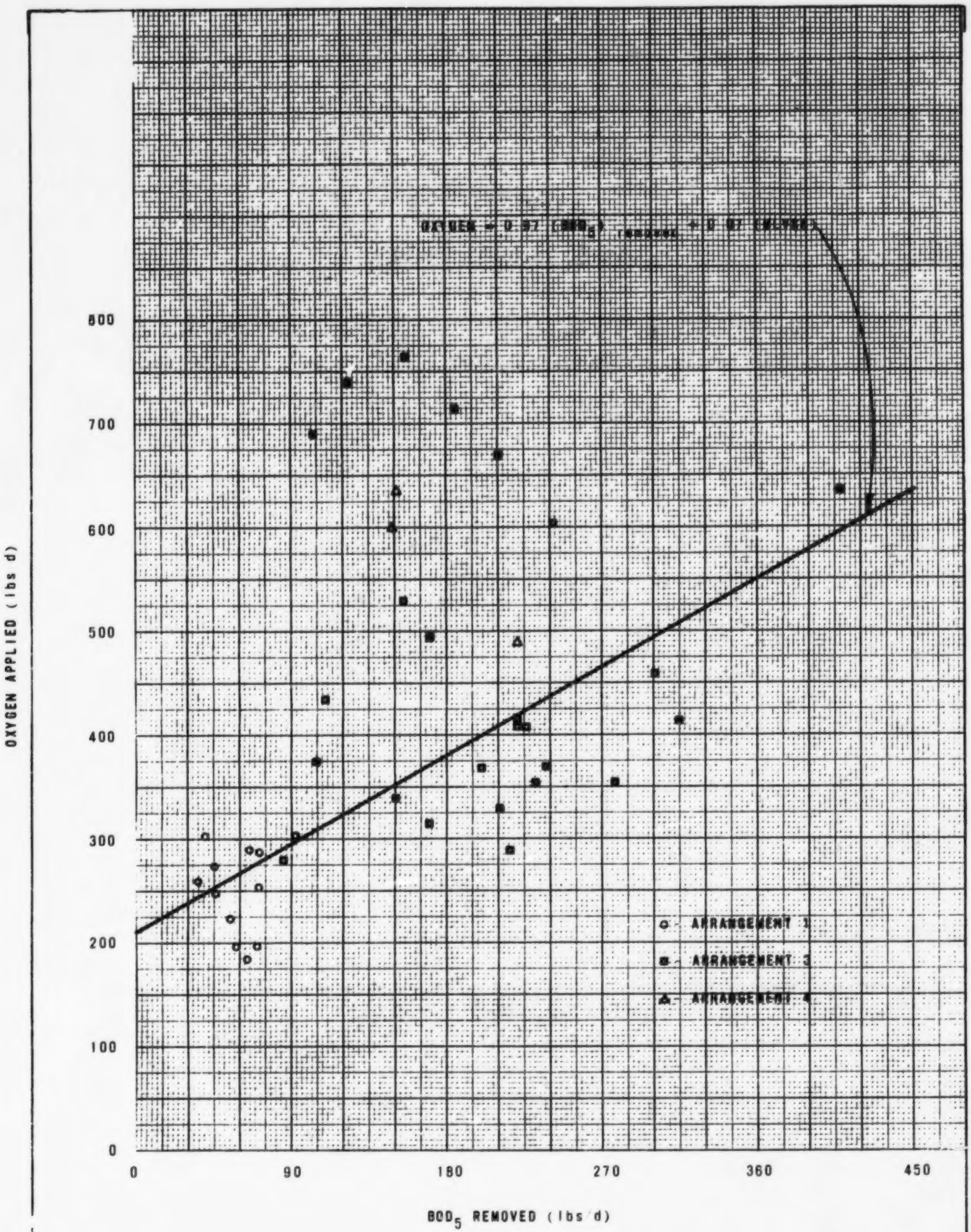
FIGURE 22

TABLE 11

O_2 APPLIED VS. BOD REMOVED*

Date	Oxygen Applied (lb per day)	BOD Removed (lb per day)	Date	Oxygen Applied (lb per day)	BOD Removed (lb per day)
7/20/71	17	61	11/2/71	376	105
21	193	71	3	423	221
22	199	58	4	495	170
27	199	73	9	421	221
28	254	68	10	371	238
29	189	64	16	688	113
8/10/71	301	91	23	670	208
11	290	65	12/1/71	656	402
12	306	41	7	766	157
17	286	69	8	746	123
18	277	44	14	417	225
19	224	54	15	417	325
24	259	57	21	711	184
25	259	34	22	609	244
26	248	42	1/11/72	432	109
10/13/71	460	309	13	344	150
14	289	214	19	533	154
20	316	169	20	281	82
21	367	200	3/23/72	601	148
26	354	228	28	632	151
27	336	277	29	485	223
28	334	210			

*Data corrected to standard conditions and 3,000 mg/l MLVSS



OXYGEN TRANSFERRED VS. BOD REMOVED

TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

FIGURE 23

Additionally, the actual oxygen utilization in the aeration basin was measured on several occasions in a BOD bottle with a Yellow Springs dissolved oxygen probe. These data, given in Table 12, were adjusted to an arbitrary MLVSS concentration of 3,000 mg/l and standard condition, as shown in Table 13. These data were compared graphically to BOD removed as shown in Figure 24. The oxygen utilization curve from Figure 23 was superimposed on Figure 24. This superimposition showed the oxygen requirements determined by the two different methods to be very similar.

The oxygen requirements design criteria for the aeration basin can be taken from Figure 23. For example, 600 pounds of oxygen per day would be required to remove 400 pounds of BOD per day.

In summary, design criteria for oxygen requirements were determined by oxygenation studies. These included alpha (α) and beta (β) determinations for various percentages of NSSC wastes. They also included correlations of oxygen applied versus BOD removed.

Waste Sludge

The excess sludge from the activated sludge facility was estimated by making a material balance on the system. The excess sludge was adjusted to an arbitrary flow (1.0 mgd) and an effluent VSS concentration of 35 mg/l. The quantities of excess sludge were compared to BOD removed (Figure 25) and influent VSS (Figure 26). The wide distribution of data shown in Figures 25 and 26 would not permit a correlation to be made between the BOD removed or the influent VSS. As a result, the quantities of excess sludge could not be estimated from the data collected.

Cellulose fibers are difficult to degrade aerobically and the quantities of excess sludge can be conservatively estimated as:

$$\text{Excess sludge} = \text{Influent suspended solids} + 0.47\,(\text{BOD})\ \text{removed} - \text{Effluent suspended solids}$$

This expression does not reflect the VSS loss due to endogenous respiration. The inert VSS (cellulose fiber) in the raw settled NSSC waste will not permit the theoretical endogenous respiration constant to be applied to MLVSS.

In summary, no definite conclusion could be reached as to the amount of excess sludge produced from normal operation of the extended aeration process.

The major findings from the extended aeration pilot plant studies are as follows:

1. There were no appreciable performance differences due to changes in the percentage of NSSC wastewater. VSS removal of blended influent improved the quality of the effluent at a given unit process loading.

TABLE 12

O_2 UPTAKE
AERATION BASIN DATA

9/21/71		9/21/71		9/22/71		10/14/71		10/14/71	
Time (min)	DO (mg/l)	Time (min)	DO (mg/l)	Time (min)	DO (mg/l)	Time (min)	DO (mg/l)	Time (min)	DO (mg/l)
0	9	0	9.0	0	9.4	0	4.7	0	6.1
0.5	4.5	0.5	5.5	0.5	6.7	0.5	2.7	0.5	2.9
1.0	1.7	1.0	2.0	1.0	4.5	1.0	1.8	1.0	1.9
1.5	0.7	1.5	0.6	1.5	2.7	1.5	1.3	1.5	1.5
2.0	0.3	2.0	0.1	2.0	1.3	2.0	1.0	2.0	1.1
2.5	0.2	2.5	0	2.5	1.0	2.5	0.8	2.5	0.8
3.0	0.1	–	–	3.0	0.6	3.0	0.6	3.0	0.5
3.5	0	–	–	3.5	0.4	3.5	0.5	3.5	0.1
–	–	–	–	4.0	0.3	4.0	0.2	4.0	0
–	–	–	–	4.5	0.2	4.5	0	–	–
–	–	–	–	5.0	0.2	–	–	–	–
–	–	–	–	5.5	0.1	–	–	–	–
–	–	–	–	6.0	0.1	–	–	–	–

TABLE 13

O_2 UPTAKE VS. BOD REMOVED*

Date	O_2 Uptake x MLVSS (mg/l)	BOD Removed (mg/l)
9/21/71	94	32
9/21/71	281	32
9/22/71	134	211
10/14/71	814	356
10/14/71	1,178	369

*Data corrected to standard conditions and 3,000 mg/l MLVSS

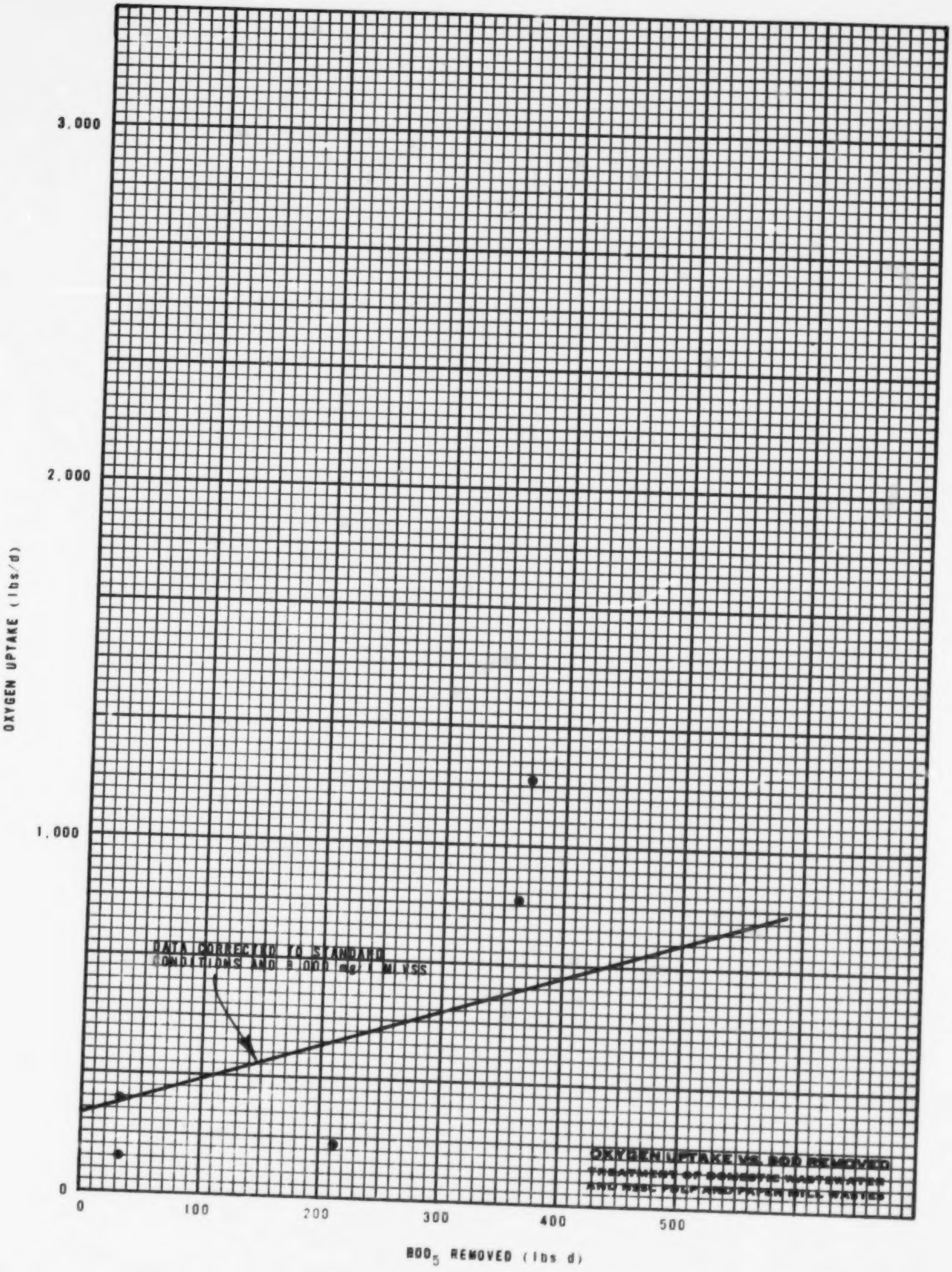

3,000
2,000
1,000
0
OXYGEN UPTAKE (lbs/d)
0
100
200
300
400
500
BOD_5 REMOVED (lbs d)
DATA CORRECTED TO STANDARD
CONDITIONS AND 3,000 mg/l MLVSS
OXYGEN UPTAKE VS. BOD REMOVED
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

FIGURE 24

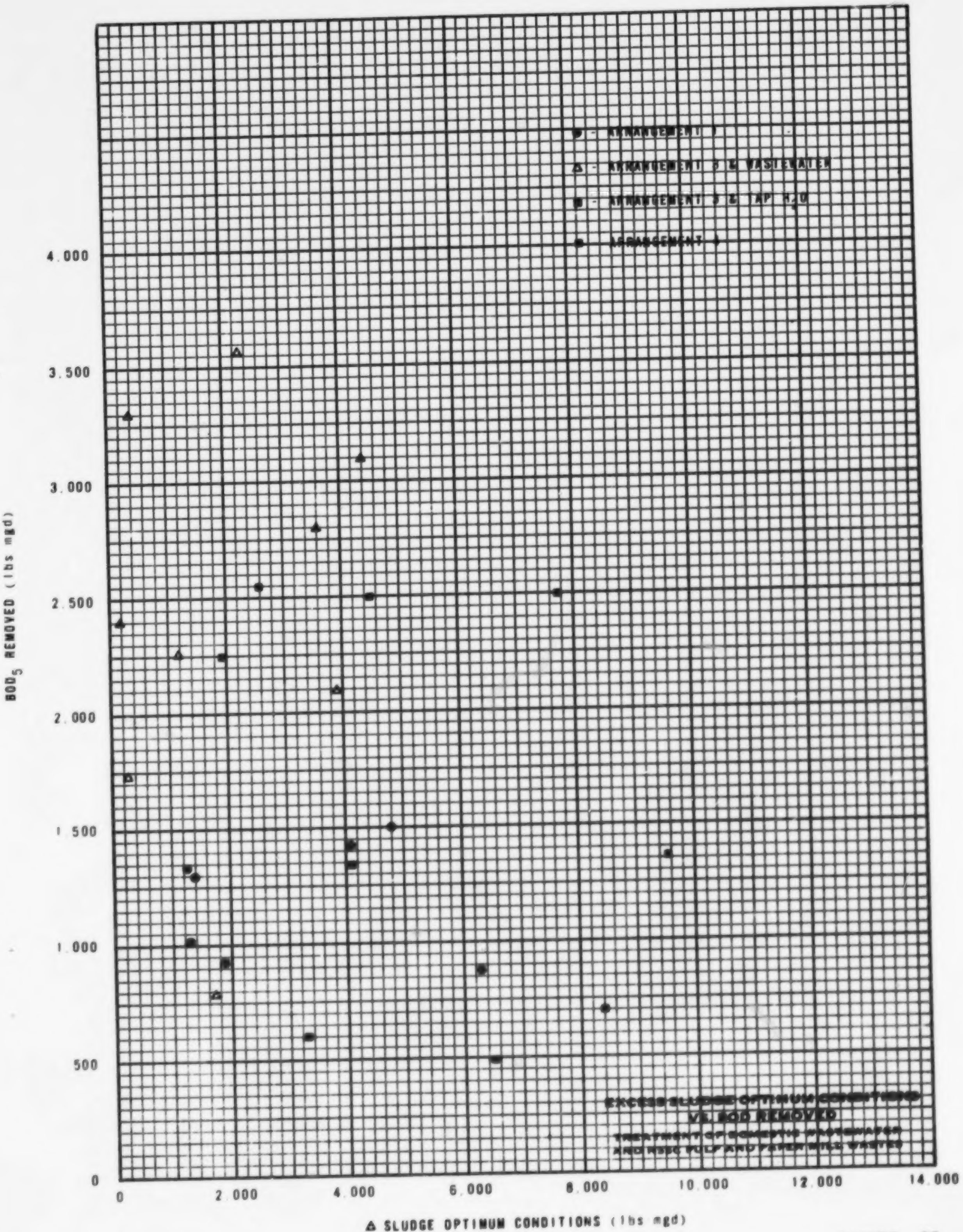

● - ARRANGEMENT 1
△ - ARRANGEMENT 3 & WASTEWATER
■ - ARRANGEMENT 3 & TAP H_2O
● - ARRANGEMENT 4
EXCESS SLUDGE OPTIMUM CONDITIONS
VS. BOD REMOVED
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES
BOD_5 REMOVED (lbs mgd)
4.000
3.500
3.000
2.500
2.000
1.500
1.000
500
0
0
2.000
4.000
6.000
8.000
10.000
12.000
14.000
△ SLUDGE OPTIMUM CONDITIONS (lbs mgd)

FIGURE 25

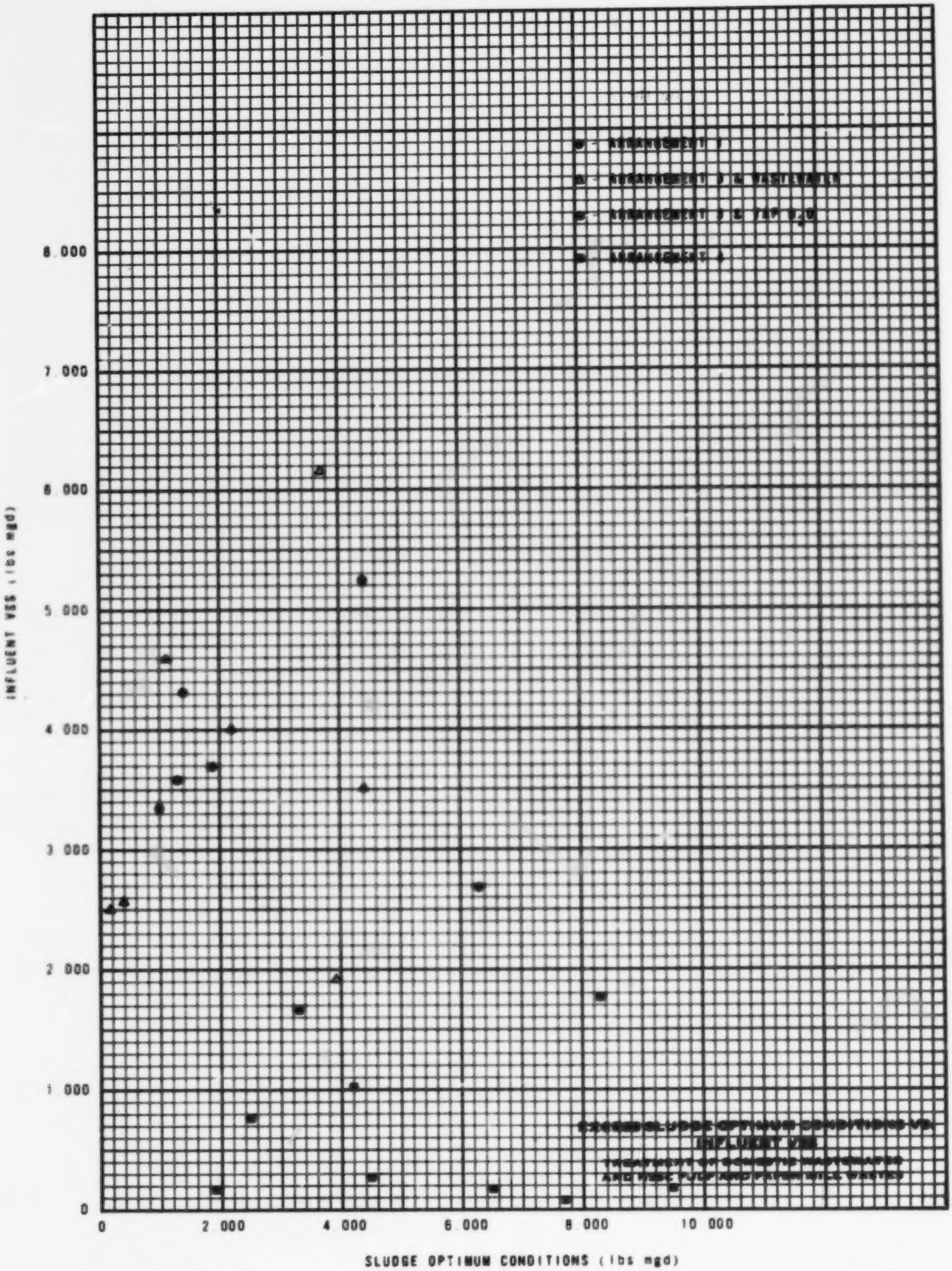

● - ARRANGEMENT 1
▲ - ARRANGEMENT 3 & WASTEWATER
■ - ARRANGEMENT 3 & TAP H_2O
■ - ARRANGEMENT 4
EXCESS SLUDGE OPTIMUM CONDITIONS VS. INFLUENT VSS
TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES
INFLUENT VSS (lbs mgd)
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
0
2 000
4 000
6 000
8 000
10 000
SLUDGE OPTIMUM CONDITIONS (lbs mgd)

FIGURE 26

2. Of the three arrangements tested, biofiltration provided the greatest single improvement in effluent quality of the aeration basin at a given process loading.

3. Alpha and Beta values depended greatly upon the percentage of NSBC wastewater present, and the values ranged from 0.42 to 0.88 and 0.42 to 0.93, respectively.

4 Oxygen requirements were determined to be 0.97 pounds per pound of BOD removed plus 0.07 pounds of oxygen per pound of MLVSS in the aeration basin.

SECTION X

FINAL CLARIFICATION

The separation of the activated sludge from the aeration basin effluent was accomplished with a clarifier with sludge rakes and a hopper bottom. The clarifier was operated for the duration of the study–May, 1971, through April, 1972. The unit was evaluated according to its operating performance at various overflow rates, water temperatures and wastewater composition.

Operation

The effective size of the final clarifier was 15 feet in diameter with a sidewater depth of 12.9 feet. The unit was operated at different flows to provide variations in overflow rates, detention times and solids loading. Data was compiled based upon grab samples collected at sampling locations as shown in Figure 2, and these included the aeration basin effluent, the clarifier underflow and the final clarifier effluent.

Over the period of operation the activated treatment system encountered different food to microorganism ratios, temperatures, industrial wastewater concentrations and other conditions which influenced its performance. These factors also had some effect on consistent performance of the final clarifier.

Performance

The results of monthly average performance data on the final clarifier are shown in Table 14. It can be seen that a very high suspended solids removal of 95 percent was achieved over the study period. In addition, BOD removal was 85 percent. Figure 27 gives the relationship between the BOD and the total suspended solids removed.

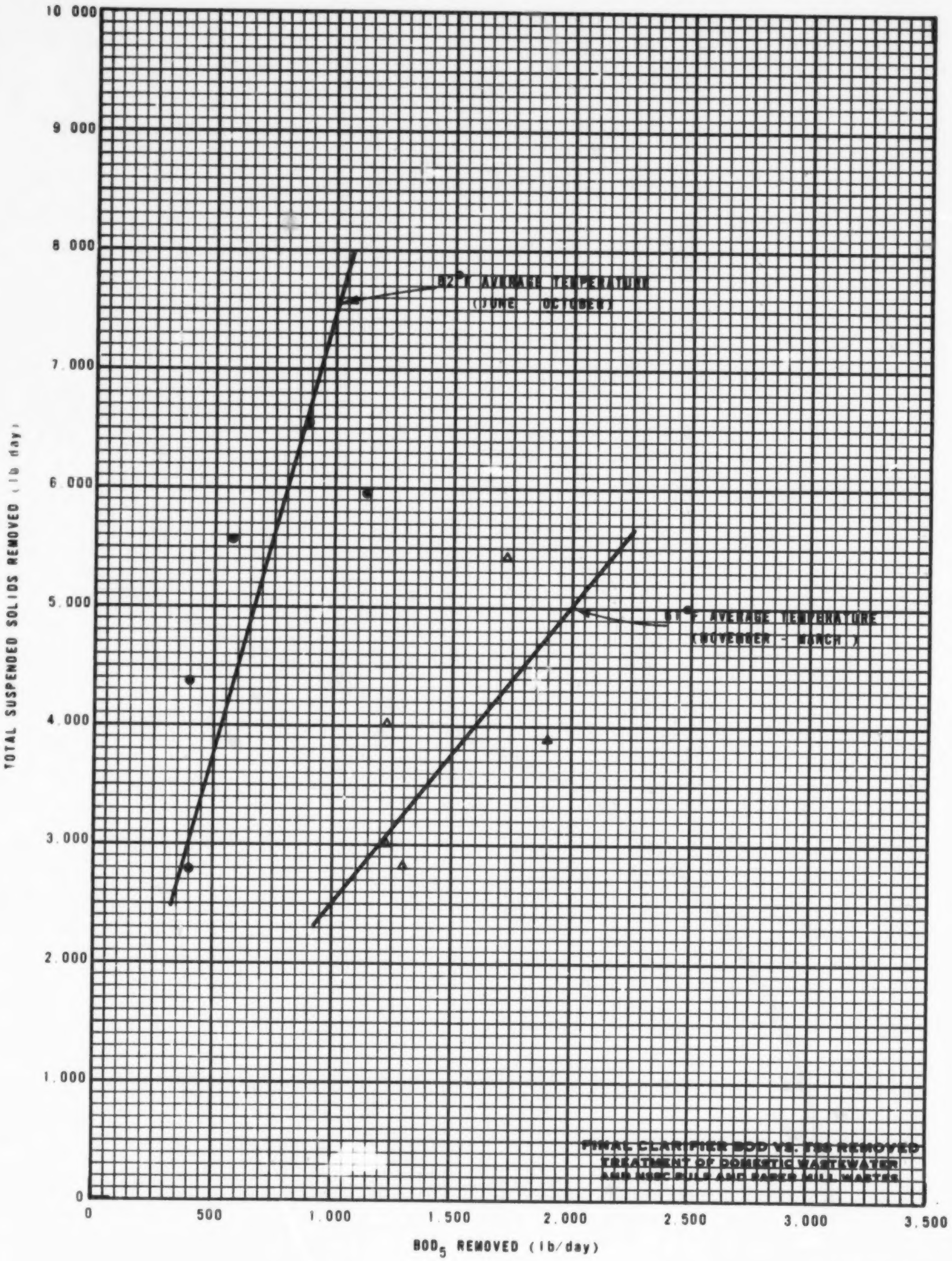
Design considerations are shown in Figure 28. From this figure, it can be seen that increases in detention time and decreases in overflow rate bring about reductions in the percentage removal of total suspended solids. It is also shown that lower temperatures reduce the performance of the clarifier, i.e., 95 percent removal requires an overflow rate of approximately 1,200 gpd/sq ft at 61° F., where almost 1,500 gpd/sq ft at 82° F. gives the same performance. The temperatures of the wastewater should be considered when the final clarifier is designed.

In the range of NSSC waste to domestic wastewater flows tested, no significant effects on final clarification were noted. At the low loadings of the extended aeration basin it is believed that settling was enhanced considerably. At higher food to microorganism ratios the settling in the final clarifier would be hampered.

TABLE 14

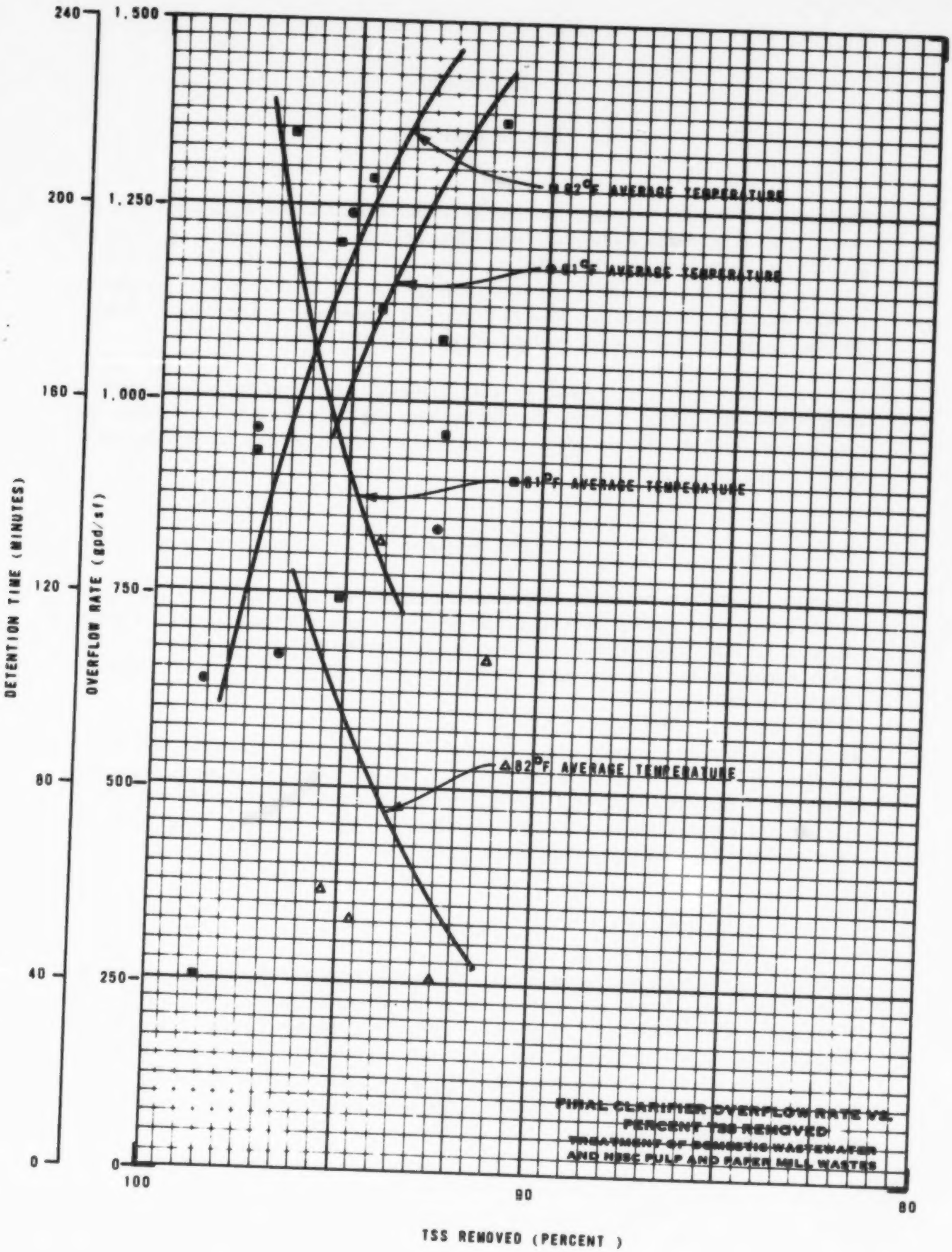
FINAL CLARIFIER PERFORMANCE
(MONTHLY AVERAGE DATA)

Month	Flow w/recirc. (1,000 gpd)	Overflow Rate (gpd/sq ft)	Water Temperature (°F.)	NSSC Waste (% Raw Flow)	Inlet TSS (lb per day)	Inlet BOD (lb per day)	Removal by Sedimentation TSS (percent)	Removal by Sedimentation BOD (percent)	Det. Time (min)	Solids Loading (lb/sq ft/day)
June	146	826	79	10	2,989	626	93	64	174	17
July	117	662	82	15	4,491	579	97	70	216	25
August	168	950	84	17	5,678	660	98	87	150	32
September	112	634	86	42	6,615	1,185	99	74	228	37
October	217	1,228	77	18	6,210	1,242	94	92	120	35
November	210	1,188	66	16	5,657	1,762	96	97	120	32
December	238	1,347	64	19	4,254	2,062	91	92	108	24
January	224	1,268	59	22	4,196	1,431	95	85	114	24
February	167	945	54	24	3,242	1,348	93	91	150	18
March	196	1,109	61	14	2,975	1,353	94	96	130	17
Average	180	1,019	71	19	4,631	1,225	95	85	151	26



FINAL CLARIFIER BOD VS. TSS REMOVED
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

FIGURE 27



FINAL CLARIFIER OVERFLOW RATE VS.
PERCENT TSS REMOVED
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

FIGURE 28

SECTION XI

COLOR REMOVAL

Paper mill wastewaters are noted for their color problems. The raw wastewater from the neutral sulfite semichemical pulp and paper waste has a deep brown-black color. Chemical precipitation with lime as a coagulant at various pH levels has been the most widely accepted method of color control. However, massive dosages of lime often are required to produce adequate reductions in color and the process may involve several steps. As a result, the process requires recalcining of the lime and is usually very expensive.

Laboratory studies were conducted on various ratios of NSSC and domestic wastewater using massive lime dosage followed by chlorination. The test procedures and findings are discussed in depth but the economics of this type of treatment were not investigated in detail.

Test Procedure

The color removal studies were conducted using a jar test procedure. The wastewater samples which were studied were composed of NSSC waste, and one part NSSC waste to one part domestic wastewater. In the precipitation studies only hydrated lime was used, which is native to the Harriman area. The chlorine source for the chlorination studies was calcium hypochlorite.

The jar test procedure consisted of dosing batch samples of the wastewater with known quantities of lime. The wastewater and lime were mixed rapidly for 15 seconds, flocculated slowly for 15 minutes and allowed to settle. The supernatant was chlorinated after the pH was adjusted to neutrality and the color determination was made. After chlorinating, the color was again measured by a colorimeter at a pH of 7.

Findings

Findings from the color removal studies are reported in Table 15. These studies include the massive lime treatment and chlorination. The results of the analyses on different mixes of NSSC and domestic wastewater are given in Figures 29-32. In Figure 29, it can be seen that increased dosages of lime on the NSSC waste reduced the APHA color significantly. The lowest color achieved was approximately 7,500 APHA units at 32,000 mg/l of lime. In the case of the one to one wastewater mixture, a dosage of slightly more than 22,000 mg/l gave the best color quality (Figure 30).

TABLE 15

RESULTS OF COLOR REMOVAL STUDIES

Ca O Dosage (mg/l)	Chlorine Dosage (mg/l)	pH (After Treatment)	Color at pH 7.0 (APHA Units)
		100 Percent NSSC Wastes	
0	0	–	24,250
7,570	0	11.5	22,850
7,570	0	7.0	17,160
7,570	800	7.0	10,350
7,570	600	7.0	12,800
7,570	400	7.0	14,750
7,570	200	7.0	15,850
15,140	0	11.8	14,200
15,140	0	7.0	12,950
15,140	800	7.0	5,940
15,140	600	7.0	7,550
15,140	400	7.0	10,100
15,140	200	7.0	11,275
22,710	0	11.85	10,250
22,710	0	7.0	9,550
22,710	800	7.0	3,900
22,710	600	7.0	5,650
22,710	400	7.0	8,070
22,710	200	7.0	9,100
30,280	0	12.0	8,100
30,280	0	7.0	7,820
30,280	800	7.0	2,015
30,280	600	7.0	4,060
30,280	400	7.0	6,435
30,280	200	7.0	8,110
37,850	0	12.05	7,650
37,850	0	7.0	8,100
37,850	800	7.0	4,350
37,850	600	7.0	4,900
37,850	400	7.0	5,700
37,850	200	7.0	7,500

TABLE 15 (Continued)

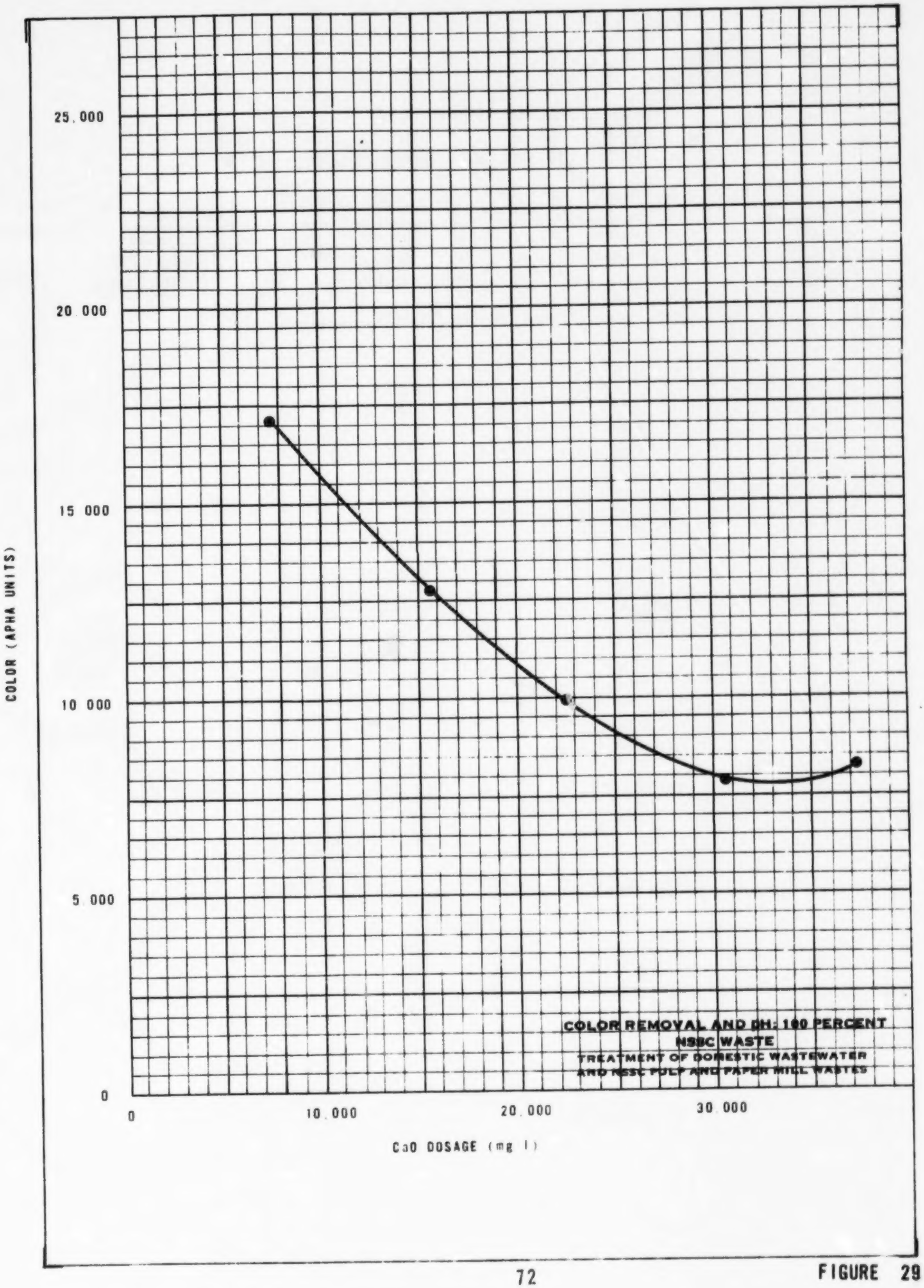
RESULTS OF COLOR REMOVAL STUDIES

Ca O Dosage (mg/l)	Chlorine Dosage (mg/l)	pH (After Treatment)	Color at pH 7.0 (APHA Units)
	50 Percent NSSC Waste—50 Percent Domestic Wastewater		
5,680	1,000	7.0	1,440
5,680	800	7.0	1,720
5,680	600	7.0	2,800
5,680	400	7.0	5,275
5,680	200	7.0	6,500
0	0	6.6	12,200
7,570	0	12.2	7,360
7,570	0	7.0	4,290
7,570	1,000	6.9	1,120
7,570	800	7.0	1,130
7,570	800	7.0	925
7,570	600	7.0	1,180
7,570	600	6.9	1,815
7,570	400	7.0	2,640
7,570	400	6.9	3,900
7,570	200	7.0	3,960
7,570	200	6.9	4,950
11,355	1,000	7.0	950
11,355	800	7.0	1,015
11,355	600	7.0	1,150
11,355	400	7.0	2,880
11,355	200	7.0	4,200
15,140	0	12.4	6,250
15,140	0	7.0	3,060
15,140	800	7.0	650
15,140	600	7.0	672
15,140	400	7.0	1,140
15,140	200	7.0	2,930

TABLE 15 (Continued)

RESULTS OF COLOR REMOVAL STUDIES

Ca O Dosage (mg/l)	Chlorine Dosage (mg/l)	pH (After Treatment)	Color at pH 7.0 (APHA Units)
50 Percent NSSC Waste–50 Percent Domestic Wastewater			
22,710	0	12.5	5,320
22,710	0	7.0	2,665
22,710	2,000	7.0	189
22,710	1,000	7.0	277
22,710	800	7.0	630
22,710	800	12.5	378
22,710	800	7.0	650
22,710	600	7.0	638
22,710	600	7.0	468
22,710	600	7.0	650
22,710	400	7.0	830
22,710	400	7.0	780
22,710	200	7.0	2,600
22,710	200	7.0	2,210
45,420	1,000	8.5	136
45,420	800	8.5	176
45,420	600	8.5	240
45,420	400	8.5	488
45,420	200	8.5	1,440
15 Percent NSSC Waste–85 Percent Domestic Wastewater			
0	0	–	3,750
757	0	9.7	5,150
3,785	0	10.9	1,470
5,678	0	–	1,160
7,570	0	10.6	1,130
11,355	0	–	920



COLOR REMOVAL AND pH: 100 PERCENT NSSC WASTE

TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES

FIGURE 29

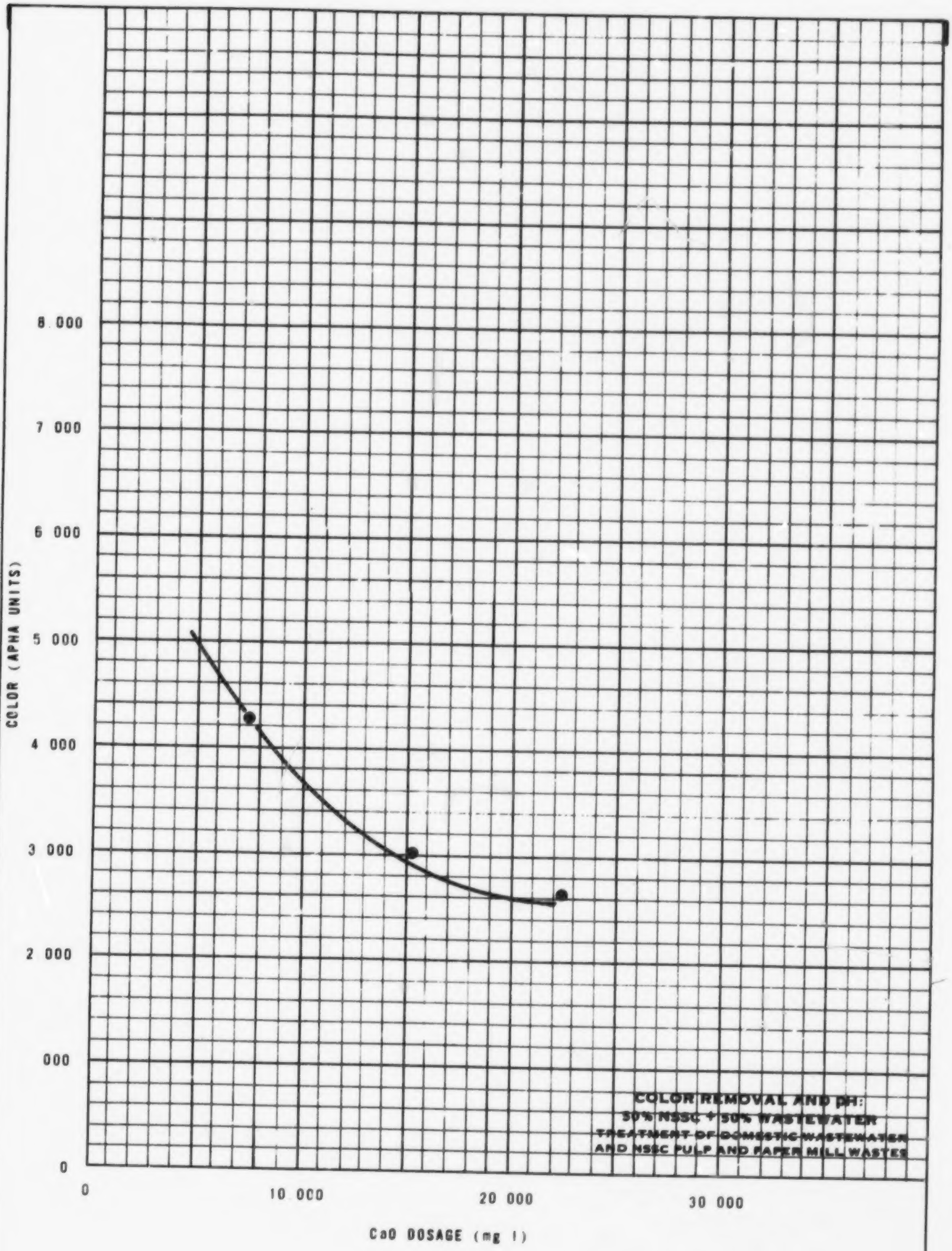
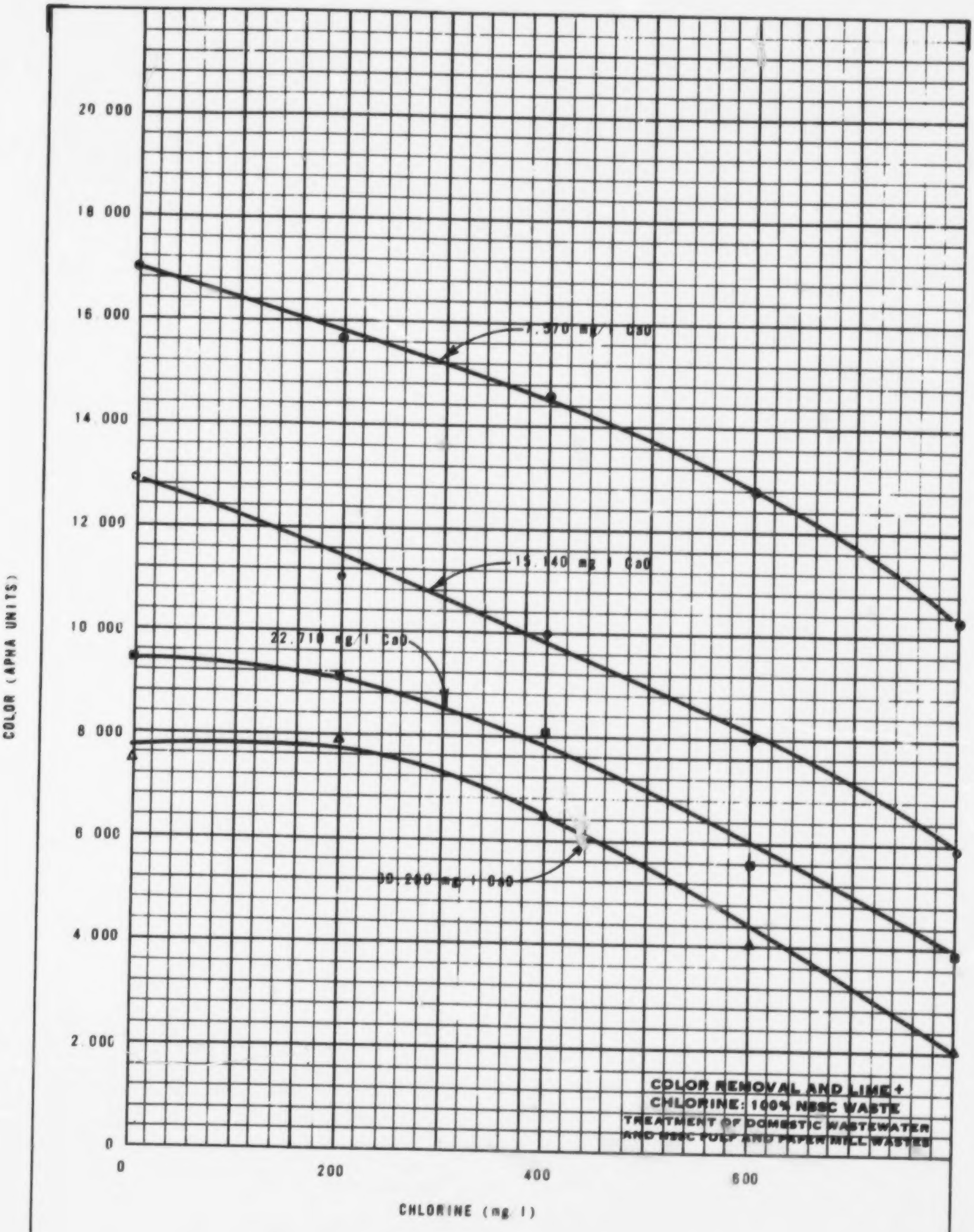

8 000
7 000
6 000
5 000
4 000
3 000
2 000
000
0
COLOR (APHA UNITS)
0
10 000
20 000
30 000
CaO DOSAGE (mg l)
COLOR REMOVAL AND pH:
50% NSSC + 50% WASTEWATER
TREATMENT OF DOMESTIC WASTEWATER
AND NSSC PULP AND PAPER MILL WASTES

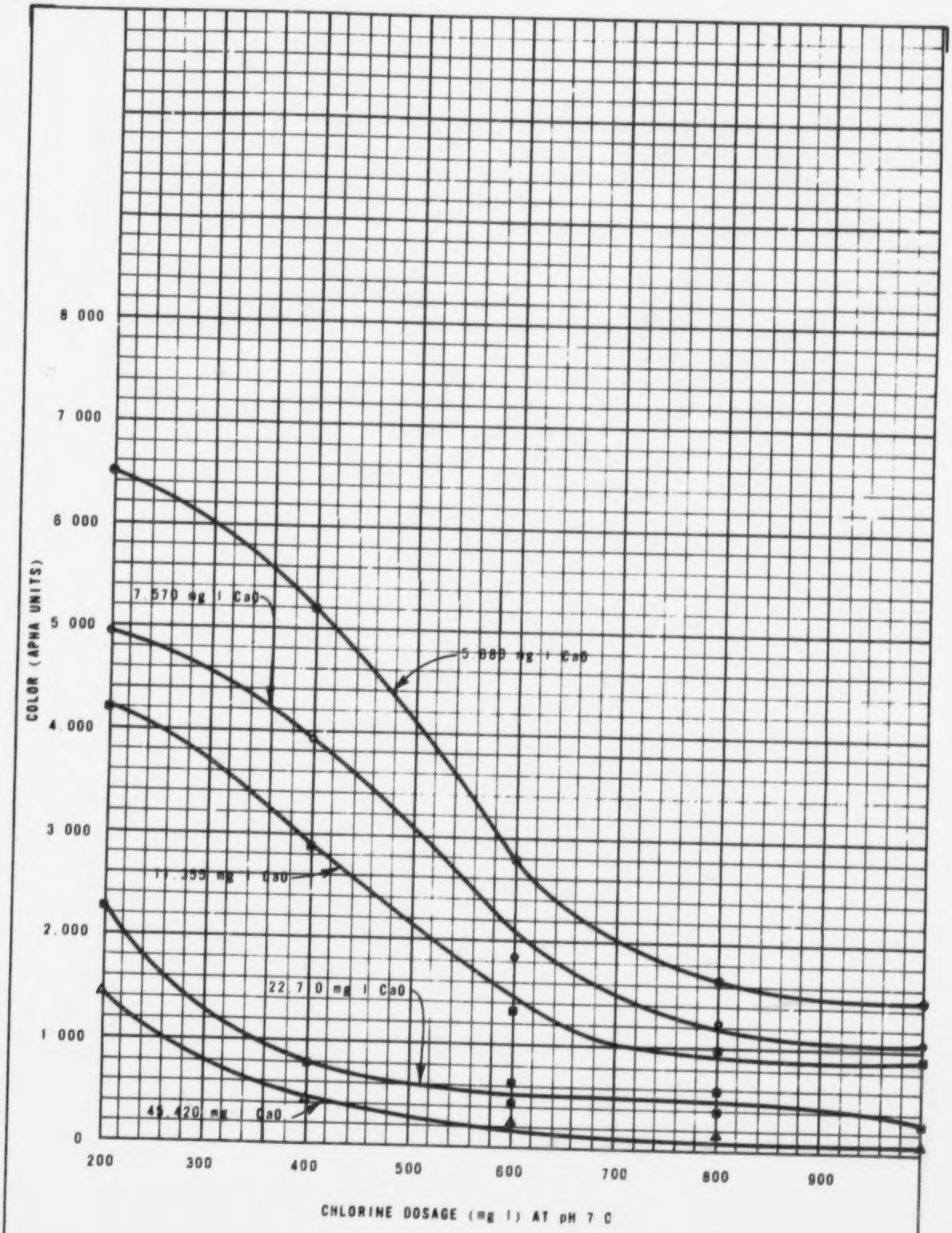
FIGURE 30



COLOR REMOVAL AND LIME+ CHLORINE: 100% NSSC WASTE

TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES

FIGURE 31



COLOR REMOVAL AND LIME + CHLORINE: 50% NSSC + 50% WASTEWATER

TREATMENT OF DOMESTIC WASTEWATER AND NSSC PULP AND PAPER MILL WASTES

FIGURE 32

Chlorination of the NSSC wastewater after massive lime treatment reduced its color to as low as 2,000 APHA units. This is shown in Figure 31. A similar reduction is shown by Figure 32 where the NSSC wastewater diluted with domestic wastewater was reduced to 100 APHA units. In this case, increased chlorination did not bring about further reductions in color for chlorine dosages above 800 mg/l.

Overall, the lime treatment was very effective and chlorination reduced the color further. However, based upon the laboratory results, the dosages of lime would be as high as 45,420 mg/l or up to 190 tons per million gallons of wastewater to be treated. This would require investigation of a lime reuse process, such as recalcining, in order to determine the economic feasibility of color removal by this method. Chlorination would appear to be a relatively small proportion of the total chemical cost of color removal.

SECTION XII

DISINFECTION

Disinfection studies on the treated NSSC and domestic wastewater using chlorine and chloramines were conducted in the laboratory from November, 1971, through March, 1972.

Procedure

Total and fecal coliform analyses using the membrane filter method, as described in the 13th edition of *Standard Methods for the Examination of Water and Wastewater*, were run at the pilot plant site to evaluate effluent disinfection.

The waste entering and leaving the chlorine contact chamber with no chemicals added was analyzed for total and fecal coliform for one month to establish a baseline for future comparison. Then laboratory studies on the effect of chlorine and combination of chlorine and ammonia application, application sequence and contact time on disinfection were made. The contact time included both the mixing time between the addition of the first and second chemical, and the mixing time of the combined chemicals and the waste.

The mixing time between the addition of the first and second chemical was varied from 3 to 45 minutes. The mixing time of the combined chemicals and the waste was varied from 5 to 78 minutes. Chlorine followed by ammonia and ammonia followed by chlorine application sequences were evaluated. Chlorine and ammonia application ranged from 10 – 40 mg/l and 0 – 40 mg/l, respectively.

Results

The results of the disinfection studies are shown in Tables 16 through 21. Table 16 shows the baseline total and fecal coliform determinations. The effects of varying the application and the application sequence are shown in Tables 17-20. The effects on the effluent of adding chlorine alone are shown in Tables 20 and 21. The effects of varying the contact time are shown in Tables 18 and 19.

The contact time studies were run concurrently with application and sequence studies. Recommended contact times of 5 minutes for the mixing of the waste and ammonia and 15 minutes for the mixing of the combined waste and chemicals after chlorine is added were reached by choosing those minimal times which resulted in consistent 100 percent coliform removal. Contact time evaluations were hindered by the fact that other parameters were also varied during that period.

TABLE 16

DISINFECTION STUDIES
COLIFORM BASELINE DETERMINATION

Date	Influent Coliform Count (MPN)		First Chemical Added Concentration (mg/l)		Contact Time First Chemical and Waste	Second Chemical Added Concentration (mg/l)		Contact Time Both Chemicals and Waste	Effluent Coliform Count (MPN)		Coliform Removal Efficiency (percent)	
	Total	Fecal	NH_3	Cl	(min)	NH_3	Cl	(min)	Total	Fecal	Total	Fecal
10/7/71	28,000	–			No Chemicals Added				30,000	–	–	–
10/8/71	160,000	120,000			"				120,000	–	–	–
10/11/71	40,000	33,000			"				28,000	–	–	–
10/12/71	24,000	26,000			"				24,000	–	–	–
10/13/71	100,000	18,000			"				70,000	–	–	–
10/18/71	240,000	2,000			"				240,000	–	–	–
10/19/71	36,000	5,000			"				11,000	–	–	–
10/20/71	23,000	11,000			"				23,000	–	–	–
10/27/71	35,000	1,000			"				31,000	–	–	–

TABLE 17

DISINFECTION STUDIES
APPLICATION AND SEQUENCE EVALUATION

Date	Influent Coliform Count (MPN)		First Chemical Added Concentration (mg/l)		Contact Time First Chemical and Waste	Second Chemical Added Concentration (mg/l)		Contact Time Both Chemicals and Waste	Effluent Coliform Count (MPN)		Coliform Removal Efficiency (percent)	
	Total	Fecal	NH_3	Cl	(min)	NH_3	Cl	(min)	Total	Fecal	Total	Fecal
11/1/71	10,000	12,000	–	35	3	0	–	68	5,000	2,300	50	81
11/2/71	38,000	N.D.	40	–	3	–	35	68	100	N.D.	99	–
11/3/71	4,000	56,000	20	–	3	–	18	68	400	42,000	90	100
11/8/71	12,000	18,000	40	–	3	–	20	72	200	N.D.	99	100
11/9/71	4,000	1,000	–	40	3	0	40	72	N.D.	N.D.	100	100
11/10/71	7,000	800	–	30	3	0	30	72	700	200	90	75
11/15/71	14,000	2,700	–	15	3	0	15	78	28,000	140,000	–	–
11/16/71	12,000	30,000	20	–	3	–	15	78	3,000	N.D.	75	100
11/17/71	12,000	6,000	15	–	3	–	15	78	N.D.	N.D.	100	100
11/22/71	2,000	17,000	–	10	3	0	10	46	5,000	14,000	–	18
11/23/71	16,000	29,000	–	15	3	0	15	40	8,000	16,000	50	45
11/27/71	15,000	16,000	–	15	3	0	15	37	6,000	8,000	60	50
11/29/71	20,000	10,000	8	–	3	–	15	41	10,000	5,000	50	50
11/30/71	6,000	7,000	10	–	3	–	15	41	N.D.	N.D.	100	100

N.D. – None Detected

TABLE 18

DISINFECTION STUDIES
APPLICATION, SEQUENCE, AND CONTACT TIME EVALUATION

	Influent Coliform Count (MPN)		First Chemical Added Concentration (mg/l)		Contact Time First Chemical and Waste	Second Chemical Added Concentration (mg/l)		Contact Time Both Chemicals and Waste	Effluent Coliform Count (MPN)		Coliform Removal Efficiency (percent)	
Date	Total	Fecal	NH_3	Cl	(min)	NH_3	Cl	(min)	Total	Fecal	Total	Fecal
12/1/71	12,000	10,000	15	–	3	–	15	39	3,000	10,000	75	N.D.
12/6/71	42,000	54,000	–	20	3	20	–	39	26,000	50,000	38	7
12/7/71	12,000	40,000	–	20	3	30	–	55	13,000	27,000	–	3
12/8/71	13,000	32,000	40	–	5	–	20	50	N.D.	N.D.	100	100
12/13/71	23,000	10,000	–	20	5	40	–	43	3,000	N.D.	87	100
12/14/71	8,000	4,000	–	20	5	40	–	41	7,000	N.D.	125	100
12/15/71	5,000	3,000	40	–	5	–	20	40	15,000	N.D.	–	100
12/20/71	14,000	N.D.	30	–	5	–	15	41	11,000	N.D.	21	–
12/21/71	6,000	N.D.	30	–	15	–	15	44	14,000	N.D.	–	–
12/27/71	11,000	N.D.	20	–	5	–	10	47	6,000	N.D.	45	–
12/28/71	24,000	10,000	20	–	20	–	10	42	3,000	N.D.	88	100

N.D. – None Detected

TABLE 19

DISINFECTION STUDIES
APPLICATION, SEQUENCE, AND CONTACT TIME EVALUATION

Date	Influent Coliform Count (MPN)		First Chemical Added Concentration (mg/l)		Contact Time First Chemical and Waste	Second Chemical Added Concentration (mg/l)		Contact Time Both Chemicals and Waste	Effluent Coliform Count (MPN)		Coliform Removal Efficiency (percent)	
	Total	Fecal	NH_3	Cl	(min)	NH_3	Cl	(min)	Total	Fecal	Total	Fecal
1/3/72	11,000	20,000	40	–	20	–	20	43	N.D.	N.D.	100	100
1/4/72	11,000	8,000	40	–	30	–	20	43	N.D.	N.D.	100	100
1/5/72	20,000	11,000	40	–	45	–	20	43	N.D.	N.D.	100	100
1/10/72	26,000	1,000	40	–	45	–	20	5	6,000	N.D.	77	100
1/11/72	9,000	6,000	40	–	45	–	20	15	N.D.	N.D.	100	100
1/12/72	27,000	9,000	40	–	45	–	20	15	N.D.	N.D.	100	100
1/17/72	4,000	1,000	40	–	45	–	20	15	N.D.	N.D.	100	100
1/18/72	22,000	7,000	40	–	45	–	20	15	1,000	N.D.	95	100
1/19/72	40,000	3,000	40	–	45	–	20	15	N.D.	N.D.	100	100
1/24/72	9,000	N.D.	–	20	45	40	–	15	15,000	400	–	–
1/25/72	31,000	1,000	40	–	45	–	20	15	1,000	N.D.	97	100
1/26/72	6,000	1,000	40	–	45	–	20	15	300	N.D.	95	100
1/31/72	13,000	N.D.	40	–	30	–	20	15	N.D.	N.D.	100	–
2/1/72	19,000	2,000	40	–	15	–	20	50	2,800	N.D.	85	100
2/2/72	4,000	N.D.	40	–	15	–	15	51	1,400	N.D.	65	–

N.D. – None Detected

TABLE 20

DISINFECTION STUDIES
EFFLUENT COLIFORM AFTER CHLORINATION

Date	Influent Coliform Count (MPN)		First Chemical Added Concentration (mg/l)		Contact Time First Chemical and Waste	Second Chemical Added Concentration (mg/l)		Contact Time Both Chemicals and Waste	Effluent Coliform Count (MPN)		Coliform Removal Efficiency (percent)	
	Total	Fecal	NH_3	Cl	(min)	NH_3	Cl	(min)	Total	Fecal	Total	Fecal
2/7/72	–	–	–	10	15	–	–	–	32,000	N.D.	–	–
2/8/72	–	–	–	10	15	–	–	–	20,000	N.D.	–	–
2/9/72	–	–	–	10	15	–	–	–	59,000	14,000	–	–
2/14/72	–	–	–	10	15	–	–	–	19,000	N.D.	–	–
2/15/72	–	–	–	10	15	–	–	–	17,000	1,000	–	–
2/16/72	–	–	–	10	15	–	–	–	15,000	N.D.	–	–
2/21/72	–	–	–	10	15	–	–	–	20,000	1,000	–	–
2/22/72	–	–	–	10	15	–	–	–	6,000	1,000	–	–
2/23/72	–	–	–	10	15	–	–	–	4,000	N.D.	–	–
2/28/72	–	–	–	10	15	–	–	–	8,000	2,000	–	–
2/29/72	–	–	–	10	15	–	–	–	9,000	N.D.	–	–

N.D. – None Detected

TABLE 21

DISINFECTION STUDIES
EFFLUENT COLIFORM AFTER CHLORINATION

Date	Influent Coliform Count (MPN)		First Chemical Added Concentration (mg/l)		Contact Time First Chemical and Waste	Second Chemical Added Concentration (mg/l)		Contact Time Both Chemicals and Waste	Effluent Coliform Count (MPN)		Coliform Removal Efficiency (percent)	
	Total	Fecal	NH_3	Cl	(min)	NH_3	Cl	(min)	Total	Fecal	Total	Fecal
3/1/72	–	–	–	10	15	–	–	–	2,000	2,000	–	–
3/6/72	–	–	–	10	15	–	–	–	40,000	28,000	–	–
3/7/72	–	–	–	10	15	–	–	–	50,000	1,000	–	–
3/8/72	–	–	–	10	15	–	–	–	4,000	2,000	–	–
3/12/72	–	–	–	10	15	–	–	–	20,000	35,000	–	–
3/13/72	–	–	–	10	15	–	–	–	24,000	58,000	–	–
3/14/72	–	–	–	10	15	–	–	–	7,000	N.D.	–	–
3/20/72	–	–	–	10	15	–	–	–	6,000	2,500	–	–
3/21/72	–	–	–	10	15	–	–	–	4,000	300	–	–
3/22/72	–	–	–	10	15	–	–	–	60,000	4,000	–	–
3/27/72	–	–	–	10	15	–	–	–	50,000	8,300	–	–
3/28/72	–	–	–	10	15	–	–	–	500	1,100	–	–
3/29/72	–	–	–	10	15	–	–	–	30,000	1,900	–	–

N.D. – None Detected

An example comparing the application sequences from Tables 17 – 20 with concentration of ammonia and chlorine held constant is shown below:

Date	Application Sequence	Total	Fecal
12/13/71	Chlorine followed by ammonia	87	100
12/14/71	Chlorine followed by ammonia	125	100
1/3/72	Ammonia followed by chlorine	100	100
1/4/72	Ammonia followed by chlorine	100	100

This data shows that the ammonia followed by chlorine application sequence was more effective in disinfection.

The amount of chlorine necessary to achieve 100 percent coliform removal is 40 mg/l as shown in Table 17, on November 9, 1971. The amount of ammonia plus chlorine necessary to achieve 100 percent coliform removal is 40 mg/l ammonia plus 20 mg/l chlorine as shown in Table 19 on January 3 and 4, 1972. According to current market prices for chlorine and ammonia, the combination of ammonia and chlorine is less expensive than the higher amount of chlorine. Thus, the combination of chlorine and ammonia should be more economical.

In conclusion, the disinfection studies showed that the following procedure is the most effective and economical in removing total and fecal coliform organisms:

1. Add ammonia at 40 mg/l and allow at least a 5-minute contact time.
2. After the 5-minute contact time, chlorinate at a concentration of 20 mg/l.
3. Allow at least a 15-minute contact time.
4. Discharge as effluent.

SECTION XIII

DESIGN CONSIDERATIONS

In the following subsections the design considerations are summarized and reviewed from an individual process and total treatment system standpoint. Emphasis was placed upon performance, maintenance, design factors, and other items which were believed to be of particular importance as a result of this pilot plant study. The processes covered included primary clarification, biofiltration, extended aeration, final clarification and disinfection.

Primary Clarification of NSSC Wastewater

Due to the high cellulose concentration in the raw NSSC wastewater the VSS were correspondingly high. Difficulty in removing the cellulose as VSS was one of the most significant factors in primary clarifier design.

Overflow rates from 200 to 300 gpd/sq ft resulted in average suspended solids removal efficiencies from 45 to 76 percent. Constant plugging by solids in piping and valves made sludge drawoff difficult and resulted in lower suspended solids removal efficiencies. Only minimal BOD and COD removals were achieved in the primary clarifier and these removals were almost independent of the suspended solids removal.

Biofiltration

The performance of unit processes within the pilot plant treatment system was strongly influenced by the high rate biofilter.

From a design viewpoint, the biofilter influent BOD and COD were reduced an average of only 13 to 16 percent with biofilter loadings averaging 260 to 290 pounds of BOD per day per thousand cubic feet of filter media. Primary clarification of the NSSC wastewater improved the biofilter BOD removal performance by approximately 100 percent. Increased proportions of NSSC wastewater reduced the performance of the filter to almost zero. However, comparison of operating results of the extended aeration basin with and without the biofilter markedly changed the extended aeration design requirements. Design consideration for the biofilter should be based on the effect it has on the performance of the extended aeration process and not on the reductions in BOD.

Extended Aeration

It was concluded in Section IX of this report that optimal extended aeration efficiency occurred when the raw NSSC waste was clarified and the combined NSSC-domestic wastewater was treated by biofiltration.

The process loadings, i.e., pounds of BOD per pound of MLVSS per day, should be less than 0.2 to obtain desirable effluent quality. Also, as long as this loading is maintained, the temperature will have little effect on the removal efficiency of the aeration basin.

The nutrients in the combined NSSC-domestic wastewater were sufficient to maintain biological activity in the aeration basin.

A range of 200 to 10,000 pounds of excess sludge was produced when 500 to 3,500 pounds of BOD were removed per day. This depended largely on the aeration basin influent VSS of the NSSC waste. Variations in the recirculation ratio of 5 to 75 percent did not affect significantly the aeration basin efficiency.

Oxygen requirements for the extended aeration basin can be taken from Figure 23 where it is shown that approximately two to three pounds of oxygen are required to remove one pound of BOD in the aeration basin. This relatively high oxygen demand was probably caused in part by the high oxygen demand of the sulfites in the NSSC waste.

Final Clarification

The effects of several operating conditions on solids settling were demonstrated.

The following operating parameters were maintained:

Operating Parameters	Range of Values
Overflow Rate	600 to 1,300 gpd/sq ft
Process Loading	0.1 to 0.2 lb BOD/lb MLVSS/day
Detention Time	1.5 to 4 hours
Temperature	54° to 86° F.

As a result, the final clarifier operated at a 91 to 99 percent TSS removal efficiency and 64 to 97 percent BOD removal.

Disinfection

The best disinfection results were achieved through the addition of 40 mg/l ammonia and 20 mg/l chlorine. The contact time after the addition of ammonia was at least 5 minutes. After the addition of chlorine, the contact time was 15 minutes prior to discharge.

SECTION XIV

ACKNOWLEDGMENTS

Mr. Stanley D. Kelley, Manager of the Harriman Utility Board, is acknowledged for his support throughout the project. Mr. Amos G. Stuehser, Superintendent of Water and Sewer Systems, Harriman Utility Board, was Project Director. Mr. Stuehser and associates are acknowledged for analytical work and operation of the pilot plant.

The pilot plant facility was designed by Black, Crow and Eidsness, Inc., Consulting Engineers, under the guidance of Dr. James B. Goodson and Mr. Robert E. Rader. Project coordination and technical assistance were provided by Mr. Philip J. Farrell and his staff at Black, Crow and Eidsness, Inc.

The support of the project by the Water Quality Office, Environmental Protection Agency and the assistance provided by Mr. Edmond Lomasney as Project Officer is acknowledged with sincere thanks.

SECTION XV

REFERENCES

Brosig, A. Jr., *et al.*, "Activated Sludge Joint Treatment of Pulp and Paper Effluent with Municipal Sewage," *TAPPI*, 54, 386 (1971).

Eckenfelder, William W., *Industrial Water Pollution Control*, McGraw-Hill Book Co., New York, N. Y. (1966).

Eckenfelder, William W., *Manual of Treatment Processes*, Water Resource Management Series, Vol. 1 (1968).

Florida State Board of Health, *Sewage Guide*, 57-62 (1970).

Hammerhill Paper Company and Erie, Pennsylvania, *Joint Municipal and Semichemical Pulping Waste Treatment*, (July, 1969).

Spruill, E.L., "Paper Mill Waste: Treatment for Color Removal," *Water and Sewage Works*, Vol. 118, No. 3, 82 (1971).

Wuhrmann, K., *Advances in Biological Waste Treatment*, Pergamon Press, Oxford (1963).

Preceding page blank

SECTION XVI

GLOSSARY OF TERMS

Acid – A compound which dissociates in water to form hydrogen ions.

Activated Sludge – A flocculent assemblage of microorganisms, non-living organic matter and inorganic materials.

Aeration – Process of intimate contact between air and liquid device.

Aerobic – Living only in the presence of free oxygen.

Alkalinity – The ability of a water to accept proton, usually due to the presence of bicarbonate, carbonate and/or hydroxide.

Bacteria – One-celled microscopic organisms.

Batch Process – A process in which there is no inflow or outflow.

Biochemical Oxygen Demand (BOD) – The quantity of oxygen utilized in the biochemical oxidation of organic matterin 5 days at 20° C.

Biological Oxidation – A biochemical reaction in which materials combine with oxygen to produce energy.

Buffer – A substance in solution which makes the solution more resistant to pH changes.

Chemical Oxygen Demand (COD) – The amount of oxygen required for the chemical oxidation of organics in a liquid.

Chlorinator – A machine for feeding either liquid or gaseous chlorine to a stream of water.

Clarifier – A tank for separating solids in suspension by settling out.

C/N Ratio – The weight ratio of carbon to nitrogen in an organic system.

Coliform Organisms – A group of bacteria recognized as indication of fecal pollution.

Colorimetric Determination – An analytical procedure based on measurement, or comparison with standards, of color naturally present in samples or developed therein by addition of reagents.

Preceding page blank

Dehydrated – Free from or lacking water.

Dilution Rate – Reciprocal of retention time.

Dissolved Matter – The material in solution in a liquid.

Dissolved Oxygen (DO) – Oxygen not combined with other chemicals in water.

Effluent – A liquid, solid or gas, frequently waste, discharged or emerging from a process.

Endogenous Respiration – An auto-oxidation of cellular material that takes place in the absence of assimilable organic material to furnish the energy required for the replacement of worn-out components of protoplasm.

Equalizing Basin – A holding basin in which, by retention, variations in flow and composition of a liquid are averaged out.

Filtrate – The liquid which has passed through a filter.

Filtration – The process of separating solids from a liquid by means of a porous substance through which only the liquid passes.

Floc – A felted mass formed in a liquid medium by the aggregation of a number of fine suspended particles.

Flow Diagram – The diagrammatic representation of a works process, showing the sequence and interdependence of the successive stages.

Flumed – The transportation of solids by suspension in flowing water.

Hydrolysis – A chemical reaction in which a compound reacts with the ions of water (H + OH^-) to form a weak acid, a weak base or both.

Limiting Nutrient – That nutrient of which the concentration in the substrate limits the growth of the organism utilizing the substrate.

Mixed Liquor – Mixture of activated sludge and liquid waste.

Mixed Liquor Suspended Solids (MLSS) – Filterable material contained in mixed liquor.

Mixed Liquor Volatile Suspended Solids (MLVSS) – Filterable material in mixed liquor which will ignite when exposed to 550° C. for one hour.

Nutrient – Any substance assimilated by organisms which promotes growth and replacement of cellular components.

Oxidation – Reaction of a substance with oxygen loss of electrons by one element to another element.

Pathogenic – Causing disease.

Residue – That which remains after a part has been separated or otherwise treated.

Sedimentation – Gravitational settling of solid particles in a liquid system.

Supernatant – The liquid standing above a sediment or precipitate.

Thickening Tank – A sedimentation tank for concentrated suspensions.

Total Suspended Solids (TSS) – Total filterable solids in a sample.

Total Residue – Total dissolved and suspended solids in a sample.

Turbidity – The reduction of transparency of a liquid due to the scattering of light by suspended particles.

Unit Operation – A physical process which can be clearly distinguished from other processes by the fundamental principles involved. Unlike most unit processes, unit operations can be formulated in rather precise mathematical expressions.

Unit Process – A chemical or biological process which can be clearly distinguished from other processes by the fundamental principles involved.

Symbols

C = Dissolved oxygen concentration at time, t

C^* = Equilibrium dissolved oxygen concentration

t = time

W = Weight of water

K_{La} = Overall mass transfer coefficient

$$\alpha = \frac{K_{La}\text{ (waste)}}{K_{La}\text{ (tap water)}}$$

β = Ratio of saturation of DO in a waste to saturation of DO in tap water at a given concentration

SECTION XVII

APPENDIX

Table Number		Page Number
A-1	Monthly Summary of Results of Overall Plant Operation	96
A-2	Monthly Influent Wastewater Characteristics	97
A-3	Primary Treatment – Blend Tank (S-5) Effluent	99
A-4	Secondary Treatment – Aeration Basin	101
A-5	Secondary Treatment – Aeration Basin Effluent	102
A-6	Secondary Treatment – Final Clarifier (S-9)	103
A-7	Secondary Treatment – Chlorine Contact Chamber (S-10)	104

Preceding page blank

TABLE A-1

MONTHLY SUMMARY OF RESULTS OF OVERALL PLANT OPERATION*

Date	Plant Influent				Chlorine Contact Chamber Effluent (S-10)							
	BOD Loading[1] (lb/day)		COD Loading[1] (lb/day)									
	Ind.	Dom.	Ind.	Dom.	pH	BOD Loading (lb/day)	COD Loading (lb/day)	Total PO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	N-Org. (mg/l)	SS (mg/l)
1971												
March	–	90	–	243	7.6	62	203	20	10.0	0.5	5.6	–
April	186	103	397	260	7.3	111	578	23	13.0	N.D.	10.5	295
May	188	88	936	229	7.2	109	740	14	–	–	–	144
June	177	151	1,055	435	7.3	127	905	18	–	–	–	170
July	201	94	1,455	286	7.5	102	878	18	–	–	–	141
August	201	104	1,475	302	7.5	111	952	29	–	–	–	121
September	304	15	2,109	61	7.6	243	1,008	13	–	–	–	154
October	323	153	1,812	409	7.4	189	1,313	–	–	–	–	264
November	255	119	1,224	302	7.2	99	976	20	–	–	–	497
December	478	118	1,917	345	7.3	309	1,535	11	–	–	–	269
1972												
January	423	78	1,646	189	7.3	285	1,247	7	3.4	2	13.6	198
February	365	12	1,732	31	7.2	62	348	6	–	–	–	229
March	302	89	1,272	272	7.1	86	766	12	–	–	–	90

[1] Unclarified Waste

*Values represent monthly averages

N.D. – None Detected

TABLE A-2

MONTHLY INFLUENT WASTEWATER CHARACTERISTICS*

Date	BOD Loading[1] (lb/day)		COD Loading[1] (lb/day)		pH		Ortho PO_4 (mg/l)		Total PO_4 (mg/l)	
	Ind.	Dom.	Ind.	Dom.	Ind.[2]	Dom.	Ind.[2]	Dom.	Ind.[2]	Dom.
1971										
March	–	90	–	243	6.7	7.1	4	14	10	23
April	186	102	397	260	6.9	7.0	6	18	10	24
May	167	88	240	229	6.9	6.8	6	19	10	20
June	128	151	–	435	6.9	6.9	4	31	8	29
July	204	94	–	286	6.9	7.0	4	28	11	29
August	213	104	–	302	6.7	6.8	5	34	13	36
September	350	15	–	61	6.6	6.8	6	28	12	32
October	379	153	1,671	409	6.8	6.8	–	–	–	–
November	281	119	1,122	302	6.8	6.7	5	24	13	33
December	474	118	2,025	345	6.8	6.9	3	12	8	20
1972										
January	510	78	1,893	189	6.6	6.9	3	8	10	19
February	395	12	1,481	31	6.9	6.9	4	–	17	–
March	335	89	1,173	272	6.8	6.8	3	12	10	18

[1] Clarified Waste

[2] Unclarified Waste

*Values represent monthly averages

N.D. – None Detected

TABLE A-2 (Continued)

MONTHLY INFLUENT WASTEWATER CHARACTERISTICS*

Date	NH_3 (mg/l)		NO_3 (mg/l)		N-Org. (mg/l)		Total Solids (mg/l)		Suspended Solids (mg/l)	
	Ind.[1]	Dom.	Ind.[1]	Dom.	Ind.[1]	Dom.	Ind.[1]	Dom.	Ind.[1]	Dom.
1971										
March	0.5	12.0	–	0.3	-	7.0	–	–	–	–
April	N.D.	19.7	–	N.D.	27.1	11.1	11,682	427	2,140	83
May	0.1	18.3	N.D.	N.D.	31.6	8.9	12,040	401	3,139	36
June	1.0	22.4	N.D.	N.D.	34.9	9.4	12,303	499	3,544	63
July	5.2	23.0	N.D.	N.D.	55.1	9.1	11,621	501	3,649	83
August	2.7	14.5	–	–	27.3	8.6	13,637	615	3,900	79
September	1.6	19.2	26	2.8	29.3	7.0	13,362	528	3,639	76
October	–	–	–	–	–	–	12,315	551	1,488	78
November	–	–	–	–	–	–	12,628	562	1,116	105
December	–	–	–	–	–	–	11,229	444	1,527	52
1972										
January	–	–	–	–	–	–	9,735	394	864	70
February	–	–	–	–	–	–	10,584	432	1,043	86
March	–	–	–	–	–	–	10,386	382	1,430	40

[1] Unclarified Waste

*Values represent monthly averages

N.D. – None Detected

TABLE A-3

PRIMARY TREATMENT – BLEND TANK (S-5) EFFLUENT*

Date	pH	BOD (mg/l)	COD (mg/l)	Ortho PO$_4$ (mg/l)	Total PO$_4$ (mg/l)	NH$_3$ (mg/l)	NO$_3$ (mg/l)	N-Org. (mg/l)
1971								
March	–	–	–	–	–	–	–	–
April	–	–	–	–	–	–	–	–
May	7.3	333	1,035	19	15	17.3	N.D.	13.7
June	7.2	223	1,281	21	19	22.5	N.D.	10.0
July	7.2	264	1,362	17	16	22.8	N.D.	12.7
August	7.1	237	1,376	14	17	12.4	–	9.7
September	7.1	1,266	5,105	5	8	9.0	13	18.7
October	7.2	439	1,594	–	–	–	–	–
November	7.1	431	1,665	14	18	–	–	–
December	7.2	514	1,689	9	11	–	–	–
1972								
January	7.2	510	1,573	7	10	–	–	–
February	7.4	616	1,848	1	5	–	–	–
March	7.2	371	1,307	7	11	–	–	–

*Values represent monthly averages

N.D. – None Detected

TABLE A-3 (Continued)

PRIMARY TREATMENT – BLEND TANK (S-5) EFFLUENT*

Date	Total Solids (mg/l)	Volatile Solids (mg/l)	Suspended Solids (mg/l)	Retention Time (hr)	Nutrient Feed	
					NH_3 (lb)	NH_3 (ppm)
1971						
March	–	–	–	0.430	–	–
April	–	–	–	0.425	–	–
May	1,638	777	380	0.380	6.4	6.8
June	1,282	612	170	0.290	–	–
July	1,764	881	278	0.410	–	–
August	2,008	941	312	0.460	–	–
September	6,823	2,717	1,210	0.280	20.9	70
October	1,989	888	123	0.420	12.0	11.8
November	1,976	885	191	0.300	–	–
December	2,238	872	243	0.300	–	–
1972						
January	2,031	859	158	0.560	–	–
February	2,827	963	110	0.300	8.5	10.6
March	1,665	727	140	0.320	9.9	10.0

*Values represent monthly averages

N.D. – None Detected

TABLE A-4

SECONDARY TREATMENT – AERATION BASIN*

Date	Retention Time (hr)	SLR[1] (lb BOD/lb MLVSS/day)	D.O. Influent (mg/l)	O_2 Applied (lb)	SS (mg/l)	VSS (mg/l)
1971						
March	13.8	–	1.80	–	145	–
April	15.0	–	0.30	9,709	553	–
May	25.0	–	N.D.	12,740	899	622
June	21.2	0.14	0.10	10,920	2,448	2,068
July	26.0	–	0.19	11,160	4,591	3,237
August	30.5	–	0.11	12,650	4,050	3,402
September	67.1	0.08	0.64	12,700	7,069	5,509
October	25.6	0.13	0.77	13,468	3,430	2,915
November	29.5	0.09	0.65	14,720	3,233	3,107
December	20.2	0.27	–	13,826	2,146	1,959
1972						
January	22.6	0.37	2.90	11,590	2,240	1,870
February	30.3	0.07	2.70	14,100	2,328	2,045
March	22.7	0.21	2.20	12,600	1,820	1,580

[1] Sludge Loading Rate

*Values Represent Monthly Averages

N.D. – None Detected

TABLE A-5

SECONDARY TREATMENT – AERATION BASIN EFFLUENT*

Date	pH	BOD (mg/l)	COD (mg/l)	Ortho PH_4 (mg/l)	Total PO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	N-Org. (mg/l)	Fixed Solids (mg/l)	Total Solids (mg/l)
1971										
March	7.5	84	290	14	23	10.0	0.7	7.5	–	462
April	7.3	179	722	21	25	16.0	N.D.	8.2	–	1,124
May	7.3	330	1,770	22	20	5.2	N.D.	17.0	433	2,066
June	7.2	513	3,339	34	46	12.6	0.8	28.0	–	3,646
July	7.4	592	5,400	23	37	10.1	0.1	24.2	–	6,490
August	7.4	471	5,567	20	25	5.4	–	15.7	1,513	5,640
September	7.5	1,266	8,514	16	21	4.4	12.0	34.9	–	–
October	7.2	686	4,974	–	–	6.8	5.6	71.0	1,294	4,263
November	7.2	1,007	3,766	16	24	9.3	3.0	172.0	1,363	4,647
December	7.2	1,040	3,536	9	16	11.4	2.0	104.2	1,250	3,622
1972										
January	7.2	764	2,973	7	12	3.2	2.0	48.2	–	3,482
February	7.2	968	3,694	2	10	6.0	1.5	79.4	–	3,812
March	7.1	828	3,015	8	16	7.6	1.8	29.2	–	2,658

*Values represent monthly averages
N.D. – None Detected

TABLE A-6

SECONDARY TREATMENT – FINAL CLARIFIER (S-9)*

Date	Retention Time (hr)	pH	Ortho PO_4 (mg/l)	Total PO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	N-Org. (mg/l)	VS (mg/l)	SS (mg/l)
1971									
March	1.9	7.5	14	22	12.0	0.4	6.3	–	–
April	2.1	7.3	19	22	14.6	0.3	8.0	525	308
May	3.7	7.3	16	14	7.6	–	17.4	588	237
June	3.0	7.2	21	18	12.0	0.9	11.5	550	186
July	3.7	7.4	20	16	16.5	0.1	13.1	699	156
August	2.6	7.4	18	21	5.2	–	9.0	766	175
September	4.3	7.6	11	13	4.8	19.0	17.3	1,866	192
October	1.9	7.2	–	–	8.3	5.6	21.5	705	286
November	2.1	7.2	13	19	9.3	3.0	24.6	571	276
December	1.8	7.3	8	10	8.7	2.0	18.0	684	294
1972									
January	1.9	7.3	6	10	2.7	2.0	13.9	643	200
February	2.7	7.2	0.6	5	4.9	1.7	23.1	881	284
March	2.2	7.1	8	11	8.0	2.3	11.4	418	150

*Values represent monthly averages

TABLE A-7

SECONDARY TREATMENT – CHLORINE CONTACT CHAMBER (S-10)*

Date	Retention Time (hr)	pH	BOD (mg/l)	COD (mg/l)	Ortho PO_4 (mg/l)	Total PO_4 (mg/l)	NH_3 (mg/l)	NO_3 (mg/l)	N-Org. (mg/l)	SS (mg/l)	Fixed Solids (mg/l)
1971											
March	1.00	7.6	7.3	240	12	20	10.0	0.5	5.6	–	–
April	1.00	7.3	124	646	19	23	13.0	N.D.	10.5	295	53
May	0.90	7.2	115	766	15	14	–	–	–	144	72
June	0.77	7.3	108	763	23	18	–	–	–	170	64
July	0.96	7.5	111	1,023	22	19	–	–	–	141	78
August	1.10	7.5	131	1,147	22	29	–	–	–	121	93
September	2.40	7.6	760	3,009	11	14	–	–	–	154	290
October	0.90	7.4	183	1,305	–	–	–	–	–	264	90
November	1.03	7.2	95	1,078	17	20	–	–	–	497	95
December	0.71	7.3	254	1,276	10	11	–	–	–	269	101
1972											
January	0.81	7.3	274	1,258	6	7	3.4	2.0	13.6	198	106
February	1.10	7.2	254	1,450	0.4	6	–	–	–	229	138
March	0.78	7.1	95	822	8	12	–	–	–	90	69

*Values represent monthly averages

N.D. – None Detected